DEPARTMENT OF THE INTERIOR

MONOGRAPHS

OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME VII

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

SILVER-LEAD DEPOSITS

OF

EUREKA NEVADA

By JOSEPH STORY CURTIS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

LETTER OF TRANSMITTAL.

San Francisco, Cal., *January* 1, 1884.

Sir: I have the honor to transmit herewith a memoir on the Eureka Mines by Mr. J. S. Curtis. I visited the more important mines with Mr. Curtis at the conclusion of his field work, and have carefully scrutinized the conclusions drawn from it. So far as I am able to judge, the observations are correct and the inferences from them sound.

Very respectfully, your obedient servant,

G. F. BECKER,

Geologist in charge, Pacific Division.

Hon. J. W. Powell,

Director U. S. Geological Survey.

CONTENTS.

ILLUSTRATIONS.

PREFACE.

The field work upon which the following report is based was begun in July, 1881, and concluded late in 1882, the assays and many of the chemical examinations being made during the progress of the field work, as occasion required, in a temporary laboratory arranged for the purpose.

In 1879 Mr. George F. Becker made a preliminary examination of the more important mines. My report was prepared under his supervision, and I am indebted to him for much valuable advice and assistance. In 1880 Mr. Arnold Hague made a detailed survey of the general geology of the district, an abstract of the results of which appeared in the Third Annual Report of the Director. Upon this abstract I have relied for the determination of the stratigraphy and the relations of the district at large to the ore-bearing formations. I also had the advantage of spending some days in observations on the surface geology with Mr. Hague in 1881. The surface geological map published with this report is taken from Mr. Hague's atlas, which will be published with his memoir.

Mr. C. R. Brown was my assistant during a great portion of the time occupied by the field work and rendered important services in collecting specimens and in the laboratory. Mr. N. Wescoatt, formerly surveyor for the Richmond company, gave me much information in regard to the workings of the Richmond mine, furnishing maps upon which the drawings of that mine are based, as well as drawing Plate III. To Mr. E. Probert, manager, and Mr. R. Rickard, superintendent, of this company, I am also indebted for many facilities, as well as to Messrs. Bryan, Longley, Morrison, and Davis, employés. Mr. T. J. Read, superintendent of the Eureka Consolidated, not only furnished me important maps and information, but gave me every

assistance in his power in visiting the mines in his charge. Mr. Byce, foreman of the same mine, rendered me many facilities, as did also Mr. Stevens, of the company's reduction works. Mr. E. N. Robinson, superintendent, and Mr. John N. Williams, foreman, of the Albion, showed me every courtesy possible, and gave me free access to the mine Mr. Kermeen, of the Ruby-Dunderburg, gave me every attention.

To superintendents and mine-owners too numerous to mention I have to return thanks for the universally courteous treatment that I received at their hands.

J. S. C.

San Francisco, *December* 31, 1883.

BRIEF OUTLINE OF RESULTS.

From the year 1869 up to the present time (1883) Eureka District has produced about $60,000,000 gold and silver, and about 225,000 tons of lead. Owing to the fact that the deposits of this district have been more completely developed than any other of a similar character on the Pacific slope, they offer very complete opportunities for the scientific investigation of the phenomena attending this class of deposits. In several respects they resemble those of Leadville, Colorado.

The structure of Prospect Mountain and Ruby Hill, the principal mining localities in the district, is explained in detail in Chapters III. and IV. of this report. The investigation here described has resulted in showing that the dominant factor of the structure of Ruby Hill is an extensive fault which has determined the present relations of the formations, the aptitude of the ground for ore deposition, the ingress of ore-bearing solutions, and the fissure system by which the ore bodies are connected. The presence of this fault, which has been called the Ruby Hill fault, is marked by a fissure filled in places with rhyolite.

The sedimentary beds of the district are of the Cambrian, Silurian, Devonian, Carboniferous, and Quaternary periods. Hitherto no deposits of value, with one exception in the quartzite of the Silurian, have been found outside of the limestones of the Cambrian and Silurian, and they have been mostly confined to the limestones of the former age, though the deposition of the ore took place without doubt in Tertiary or post-Tertiary times. The igneous rocks of the district occurring near the mines are granite, quartz-porphyry, hornblende- and augite-andesites, rhyolite, and basalt. Granite-porphyry and dacite occur, however, in this region.

The ore above the water-level is principally composed of the minerals galena, anglesite, cerussite, mimetite, and wulfenite, with very little quartz and calcite; the gangue being for the most part hydrated oxide of iron. The ore also carries considerable gold and silver, and zinc is present probably as carbonate and silicate. Below the water-level the ore is chiefly composed of pyrite, arsenopyrite, galena, blende, and a few other sulphides, as well as silver and gold.

The ore deposits themselves are very irregular in form, sometimes resembling lodes, sometimes "stocks," and sometimes beds. Ore bodies of any size are always capped by caves or in some way connected with such openings in the rock and with fissures. This connection of ore bodies with fissures is universal in the district. The caves were probably formed since the deposition of the ore, partly by the action of water carrying carbonic acid, and partly by the shrinkage of the ore caused by decomposition. Since this last action took place the ore has in many instances been redistributed by the flow of underground waters. The former presence of these waters is shown by the stratification of portions of the ore bodies, and by traces of aqueous action exhibited by the surrounding limestone.

It is likely that the constituents of the ore were derived from some massive rock by solution, the solutions being due to the solfataric action incident to the eruption of large masses of rhyolite. They entered the limestone from below through fissures, and the greater part, at least, of the ore was deposited by direct substitution for that rock. The limestone was fissured and crushed in many directions by the various faulting movements and gave free ingress to the ore-bearing solutions, which followed the channels of least resistance and deposited the ore in masses of very irregular form.

The assays of country rock show conclusively that the materials for the ore could not have been derived from any of the sedimentary formations. The quartz-porphyry is the only igneous rock of the district in which anything but traces of the precious metals has been found, and although it does not cover much ground on the surface it may be of much more considerable extent below. The results obtained from its examination point to it as the source of the ore in its neighborhood, at least. The granite which probably underlies the formations of Prospect Mountain and Ruby Hill may also have been a source of the ore, but if such is the case the extraction of the heavy metals from it has been very complete, as when found on the surface it contains scarcely a trace of silver, gold, or lead.

The process of determining the presence of an ore body by means of exact assays of the surrounding limestone has as yet led to no practical application, although the results obtained by this method of prospecting coincide in a remarkable manner with the electrical experiments made by Dr. Barus with a view to the same object. The methods used in assaying are fully explained in the chapter on that subject.

The chances of finding ore in the deeper workings of Ruby Hill are considered to be favorable, though the quality and size of ore bodies cannot be predicted with certainty.

SILVER-LEAD DEPOSITS OF EUREKA, NEVADA.

BY J. S. CURTIS.

CHAPTER I.

GENERAL DESCRIPTION OF EUREKA DISTRICT.

Position.—Eureka Mining District is situated on the western side of the Diamond Range in the eastern part of the State of Nevada and south of the Central Pacific Railroad. The town of Eureka, which forms the business center of this region, is about 90 miles south of Palisade, a station on the above-mentioned railroad. Eureka is connected with Palisade by a narrow-gauge road. The town lies at an altitude of about 6,500 feet above sea-level, in a cañon, which, following a northerly course, enters Diamond Valley. Ruby Hill, distant about two miles west of Eureka, is the mining center of the district. On the hill which gives its name to the town are the mines which, through their large production of lead, silver, and gold, have given Eureka District a world-wide notoriety. The Ruby Hill mines are by no means the only productive mines of the district, but they are those which up to the present time have been most extensively worked and have afforded the best returns for invested capital. On account of the facilities offered for the study of mining geology, these mines are also the most interesting from a scientific point of view. They have been examined by many able geologists and mining engineers, among whom there has been great diversity of opinion in regard to the nature of the deposit.

Topography.—The surface of the country in which Eureka, Secret Cañon, and Silverado Districts are situated is broken up, by a series of cañons, into

narrow ridges or spurs which join either the Prospect Mountain ridge on the west or the main Diamond Range on the east. These spurs are separated from each other by a main cañon running from Diamond Valley on the north to Fish Lake Valley on the south. One of the principal of them, extending a little south of east from Prospect Peak, the central and highest elevation of the Prospect Mountain ridge, divides the watershed of the east side of that ridge so that the regions lying to the north and south of the crest of the spur are drained respectively by Diamond and Fish Creek Valleys. At the northern end of this cañon, near its entrance into Diamond Valley, is situated the town of Eureka. Silverado District lies a few miles east of the main cañon, in the hills south of the divide, and Secret Cañon District on the southern portion of Prospect Mountain, and its spurs west of the before-mentioned main cañon. The mines which will be described in this memoir are confined to Eureka District, which includes the northerly portion of Prospect Mountain and its spurs. Of these spurs Ruby Hill is the most important, and Adams Hill, though detached, is also to be regarded as a member of the system.

Prominent elevations.—Prospect Mountain is a narrow and steep ridge, some seven miles in length, extending from Diamond Valley to Fish Creek Valley. The mountain itself consists of an anticlinal fold which at its greatest elevation, Prospect Peak, is 9,600 feet above sea-level, and, with the exception of Diamond Peak, is the highest point in the neighborhood. From this point it descends gradually, forming irregular and rugged peaks, and is lost in the valleys on the north and south. The width of the uplift varies from a mile to a mile and a half, and is greatest in the neighborhood of Prospect Peak. The northern watershed is cut up by three long and deep cañons, Goodwin, New York, and the cañon which connects with Secret on the southern side of the divide and forms one of the principal cañons which empty into Fish Creek Valley. The western slope of Prospect Mountain is very much steeper than the eastern, and is divided into abrupt and rough ridges by short cañons which open into Spring Valley.

Ruby Hill forms the northern spur of Prospect Mountain, but the axis of its fold has a northwest direction from its junction with the main mountain. At its highest point it reaches an altitude of 7,300 feet above sea-

level, or about 700 feet above Spring Valley, which divides the Prospect Mountain ridge from the next succeeding one on the west. Although the hill has a rather steep ascent it is by no means as rugged as many parts of the mountain of which it forms a spur.

Adams Hill is a low hill, about 6,950 feet above sea-level, and is situated about half a mile north of Ruby Hill, from which it is separated by a narrow ravine leading into Spring Valley. It is somewhat lower than Ruby Hill, and presents no particular feature of topographical interest. It may be regarded as the north end of the Prospect Mountain anticlinal, and slopes off gradually toward Spring and Diamond Valleys.

Hoosac Mountain, somewhat noteworthy on account of a mine in the quartzite, lies just north of the divide between Secret Cañon and the main cañon. Its altitude above sea-level is about 8,500 feet.

History.—Ore was first discovered in this district in 1864, in New York Cañon, near the present "76" mine, and a company was organized in New York to work the mines, under the direction of Major McCoy, one of the pioneers of this region. These discovery claims, although producing some rich ore, were shortly abandoned, and the district remained uninhabited until the latter part of 1868 or the beginning of 1869, at which time Major McCoy recommenced mining operations on what is called Mineral Hill, an elevation situated a short distance south of Ruby Hill. Subsequently, in the same year, some men in his employ located the Champion and Buckeye claims on the southwest side of Ruby Hill, and shortly afterwards the Richmond and Tip-Top ground was taken up.

In Nevada in those days silver-bearing lead ores unless very rich were considered of little value, and although the outcrops of these locations exposed large quantities of such ore, little interest was taken in them until, after several unsuccessful attempts by others, Mr. G. Collier Robbins in the early part of 1870 succeeded in smelting ores from the Champion and Buckeye, if not with profit, at any rate with satisfactory metallurgical results. This induced Messrs. Buel & Bateman to bond these mines and organize the Eureka Consolidated Mining Company of San Francisco. Furnaces were then built near what now forms the north end of the town of Eureka, and active operations began upon the claims of the company.

Still later the Tip-Top and Richmond claims were sold by Messrs. Dunn & English to a company in London, and smelting works were erected, under the supervision of Mr. English, at the south end of the town. The Jackson and Phœnix companies were also incorporated in San Francisco about this time, and the explorations, which have since resulted in the production of such large amounts of lead, silver, and gold from these properties, were begun in earnest. The Maryland and other mines in Silverado District, 16 miles southeast of Eureka, were being opened during this period by an English company, and a large mill was being built at Pinto The Page & Corwin and the Geddes & Bertrand mines in Secret Cañon, south of Eureka, had been producing rich ore since 1869, and a mill was also built on the spot where the present leaching works stand. Secret Cañon at this time formed part of Eureka District, but has since been severed from it. Mr. Robbins was also developing the Kentuck and Mountain Boy claims in a range of mountains about fifteen miles west of Eureka.

It is not necessary to follow the history of Eureka through all the vicissitudes which are incident to the growth of such towns, nor to describe the different enterprises which have been undertaken and abandoned; suffice it to say, that in the course of twelve years this mining camp has been twice partially washed away by floods, once ravaged by the small-pox, and twice almost completely destroyed by fire, but remains to-day, after thirteen years of prosperity, one of the most productive mining towns on the Pacific Slope.

The number of inhabitants of the district is at present in the neighborhood of 6,000, but, as in other mining camps, a close estimate is very difficult owing to the floating character of the population.

Production.—As nearly as can be estimated the production of the precious metals up to the end of 1882 has been about sixty millions of dollars. Probably about one-third of this amount, or twenty millions of dollars, was gold. It is difficult to ascertain the quantity of lead produced, but this is approximately 225,000 tons.

GEOLOGICAL MAP OF RUBY

Map extracted from the Report on the

QUATERNARY	CARBONIFEROUS	SILURIAN			CAMBRIAN		
Mountain Quaternary	Lower Coal Measures					Hamburg Limestone	Secret Cn Shale
Q	LC		E	P	HS	H	SC

Scale 1

L AND ADJACENT COUNTRY

of Eureka District by Arnold Hague.

IGNEOUS

Prospect Mt Quartzite — PQ

Basalt — B

Pumice and Tufa — T

Rhyolite — R

Augite Andesite — A

Hornblende Andesite — HA

Quartz Porphyry — F

Granite — G

inch

3000 4000 5000

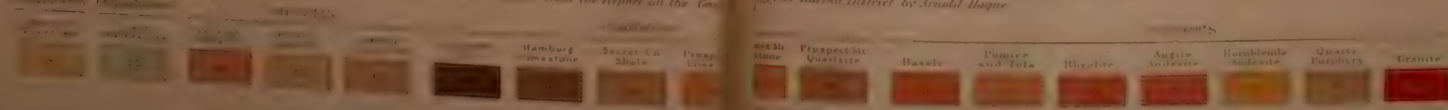
1000 2 mi

Assumed fault lines

Grade Curves 50 feet Vertical Interval

GEOLOGICAL MAP OF RUBY HILL AND ADJACENT COUNTRY

Map extracted from the Report on the Geology of Eureka District by Arnold Hague



CHAPTER II.

SURFACE GEOLOGY.

General geology.—Mr. Arnold Hague has described the general geology of this mining district,[a] as well as that of the whole region lying within a radius of ten miles from Prospect Peak, and little more is therefore necessary here than a reference to his results. The Cambrian, Silurian, Devonian, and Carboniferous are all represented in the formations of this district, though it is only in the rocks of the first two that metalliferous deposits of any kind have been found, and excepting the Hoosac mine, in the Eureka quartzite of the Silurian, it is only in the rocks of the Cambrian period that deposits of any great value have been discovered.

Formations.—Mr. Hague distinguishes the following beds in the Cambrian, beginning with the oldest: Prospect Mountain quartzite, Prospect Mountain limestone, Secret Cañon shale, Hamburg limestone, Hamburg shale. These five formations have all been laid down conformably. The rocks of the Silurian in the order of succession are Pogonip limestone, Eureka quartzite, and Lone Mountain limestone. According to Mr. Hague, the first two of these beds have been laid down conformably with the formations which represent the Cambrian, but there appears to be a non-conformity between the Lone Mountain limestone and the overlying quartzite. The rocks of the Devonian in this neighborhood are the White Pine shale and Nevada limestone, in the latter of which the mines of Alhambra Hill, in Silverado District, are situated.

Relations of the mines to the formations.—With the exception of the Hoosac mine in the Eureka quartzite, and the Bullwhacker and other mines in the Pogonip

[a] Abstract of Report on the Geology of the Eureka District, Nevada, by Arnold Hague; Third Annual Report of the Director of the U. S. Geological Survey, 1882. Mr. Hague's full report is not yet in print.

limestone on the slope north of Adams Hill, all the mines which will be discussed in this report are found either in the Prospect Mountain or Hamburg limestones. No deposits whatever have been found in the Secret Cañon shale which separates these two beds, and although it is true that pyrite, both as impregnations and in masses, as well as distinctly defined veins of quartz accompanied by calcite, has been found in the Prospect Mountain quartzite, the lowest of the sedimentary beds of the district, it has had no economic value. These occurrences moreover do not seem to be in any way connected with the deposits in limestone. As far as is known, there is no ore in the Hamburg shale.

Quartzite.—The Prospect Mountain quartzite occurs on Prospect Peak, and extends northerly, southerly, and westerly from this point, covering an area of about a square mile. It is also found in the shape of a horseshoe at the northern end of Prospect Mountain, where it divides Ruby Hill, of which it forms the lower western portion, from the main mountain. There is a third small outcrop of this rock on the west slope of Prospect Mountain, between the two above-mentioned localities. These three places are the only ones where this quartzite is found in the district. On the surface it is of a reddish color, which is no doubt due to the oxidation of pyrite, but at a depth of a thousand feet, or at a point where oxidation has not set in, it is of a grayish-white color. It is brittle, particularly near the limestone, where it is often possible to crush it in the hand. It breaks in sharp angular pieces, of which the faces of fracture have a somewhat vitreous appearance. Aboveground it is usually harder and more compact. It is evidently not even approximately pure silica, and is more or less associated with clayey material.

Prospect Mountain limestone.—The Prospect Mountain limestone composes the bulk of Prospect Mountain and Ruby Hill. It was laid down conformably on the quartzite, and to subsequent upheaval and the erosion of overlying formations owes its present prominence on the hill and mountain. Its strike is northerly, following the ridge of Prospect Mountain until it reaches Ruby Hill, where it bends round to the west, following the quartzite horseshoe. Its dip as exposed by the workings of the Ruby Hill mines is certainly much less than 40°, but owing to the absence in most places of all signs of stratifi-

cation, and to the occurrence of several faults, an exact statement of its mean dip is impossible. This dip is, however, much less than it would at first appear to be on an examination of its contact with the quartzite, as that has apparently been moved upward along the plane of its contact with the limestone, thereby crowding that rock outward. This is the case on the northern portion of Prospect Mountain, as well as on Ruby Hill. On the surface this limestone usually has a bluish-gray color. It weathers to a chalky white, and is corrugated and roughened by the mechanical and chemical action of water. In texture it is granular-crystalline, and it is frequently hard and tough. Underground it exhibits numerous varieties of habitus and color. It appears as calcite, coarse marble, hard white and black limestone, and in the neighborhood of ore bodies is usually stained from a light and dirty yellow to a deep reddish brown by oxides of iron. Considerable masses are often met with which have been crushed to a mere powder, and in the neighborhood of ore bodies it is generally more or less broken up. Numerous caves and vuggs occur in it, and it everywhere shows the action of water. Breccias of different kinds of limestone, cemented together by calcite, are quite common, and occurrences of that mineral and of aragonite are frequently met with in the openings in the rock. This limestone is sometimes found distinctly stratified, and is then usually of a dark bluish-gray color. It everywhere gives evidences of having been subjected to immense pressure.

Secret Cañon shale.—The Secret Cañon shale overlies the Prospect Mountain limestone, and forms a narrow belt which follows the course of the ridge of Prospect Mountain, and, like the above-mentioned limestone, bends round to the west on reaching Ruby Hill. This shale is of a dull bluish color, except where exposed to the atmosphere it has weathered to a dirty yellow, or where it has been subjected to the action of surface waters through fissures underground. It is often disintegrated to a mere clay. It is usually argillaceous, though sometimes it alternates with thin layers of stratified limestone, and the strata are much bent and twisted.

Hamburg limestone.—The Hamburg limestone does not differ so materially from the Prospect Mountain limestone underground as it does on the surface. As far as its physical properties are concerned, the limestone in the

Ruby-Dunderburg mine, which is in the Hamburg limestone, might be mistaken for that of Prospect Mountain. It is only through its connection with the well-established belt of Hamburg limestone that its relative age can be decided. It is hard to say what the properties of the limestone in the Hamburg mine are which make it easy to recognize the difference between it and the Prospect Mountain limestone, but they are characteristic enough to render it evident even to the casual observer that it is a different limestone. It breaks with a sharper fracture, which is probably due to the larger quantity of silica that it contains; and one or two varieties resemble quartzite in texture. The Hamburg shale differs in no essential respects from the Secret Cañon shale.

Pogonip limestone.—The Pogonip limestone forms a nearly continuous belt on the eastern slope of Prospect Mountain, and on the north and east sides of Adams Hill where that elevation merges in the valley. In this limestone the first discoveries in the district were made in New York Cañon. In it are also situated the Bullwhacker, Williamsburg, and other mines. In color this limestone does not differ much from the two limestones before described, except that it is of a brownish tinge, but it is softer, shows fewer signs of metamorphic action, and is almost everywhere distinctly stratified.

Eureka quartzite.—The Eureka quartzite composes Hoosac Peak and the entire eastern half of the mountain of that name. It also occurs as a narrow band on the west side of New York Cañon and east of the main cañon where it enters Fish Creek Valley. Its color is white, reddish, or bluish, and it is very hard and compact. In texture it is granular, and it is rarely found stratified. It is apparently nearly pure silica.

Massive rocks.—The only massive rocks which make their appearance in the metalliferous zone which is occupied by Prospect Mountain and its offshoots are granite, quartz-porphyry, and rhyolite, but hornblende-andesite is found in its neighborhood, and basalt within three miles.

Granite.—The granite crops out at Mineral Hill at the north end of Prospect Mountain, covering an area of but a few acres; and this is its only occurrence in the district. It appears between the limestone and the quartzite. It is coarse-grained, grayish in color, and very much weathered at the

surface. What its underground character may be is not known, as there have been no explorations made in it.

Quartz-porphyry.—Quartz-porphyry appears in two places north of Adams Hill. Mr. Hague assigns no definite age to this rock, but states that it is post-Cambrian. From the manner of its occurrence in the Bullwhacker mine it would appear to be of earlier origin than the ore. This rock has a reddish color on the surface and a granular texture. Where exposed underground it is white, shows considerable quartz, and contains cubes of pyrite. Neither variety is hard.

Rhyolite.—Rhyolite is abundant in the neighborhood of the mines as well as in immediate proximity to the ore. In some portions of the district it covers large areas, but in the mines it is only found in the form of dikes, which, so far as is known, have never exceeded 20 feet in width. There are particularly large outbursts of this rock at Purple Mountain near Ruby Hill and at Pinto Peak. It is of a nearly white color, sometimes with a pinkish tinge, and of various degrees of hardness.

Hornblende-andesite.—Hornblende-andesite occurs near Hoosac Mountain, where it covers a considerable territory. It is of a crystalline texture, dark color, and is considerably weathered. The last two rocks are assigned by Mr. Hague to the Tertiary age.

Peculiar formation in the Phœnix mine.—In the Phœnix mine there is an occurrence of a peculiar rock, the exact nature of which has not been determined. The position which it occupies can be seen on referring to vertical section No. 3, Plate V. As far as known it lies wholly in the quartzite. It is usually of a black color and contains large quantities of magnetite and pyrite. It is everywhere penetrated by small seams of calcite, and some specimens are composed almost entirely of that mineral and clay, which latter substance often fills cracks and fissures in the mass of the rock. Some pieces showing the least decomposition when treated with boiling chlor-hydric acid give off a great deal of carbonic acid, and the iron and other soluble substances are completely dissolved, while a white skeleton of some siliceous material is left which exhibits a cellular structure. The mass shows no signs of any stratification, and everywhere exhibits evidence of the extended metamorphism to which it has been subjected. The form in

which it occurs would indicate that it was an intruded mass of igneous rock, and this theory is in a measure sustained by the fact that specimens closely resembling rhyolite have been found in the mass. Other specimens are composed almost entirely of calcium carbonate and have unquestionably the structure of limestone. In the upper levels of the mine this rock is so much decomposed and mixed with quartzite that its boundaries are not distinct. It is very possible that it was originally an intercalated bed of limestone and has been metamorphosed by an intruded mass of rhyolite and the attending solfataric action.

CHAPTER III.

THE STRUCTURE OF PROSPECT MOUNTAIN.

Manner of upheaval.—Prospect Mountain and its adjacent spurs form an anticlinal fold of which the axial plane is usually somewhat west of the crest of the principal ridge. The course of this plane is nearly due north and south, except at Ruby Hill, where it turns toward the west. At those places on the western side of the mountain where the strata have been laid bare by mining explorations, the traces of bedding are so rare that it is impossible to form an accurate idea of the prevailing angle of dip.

When the alternating beds of shale and limestone, which at present form the mountain, were folded and uplifted an enormous crushing and grinding force was exerted upon the different members of the series. Those rocks, such as the shales, which were flexible and would give, stood the test of this great pressure with the least injury to their physical structure, and, although they were much disturbed and flattened out, retained their original character. With the limestones it was otherwise. Their hard and compact nature and their tendency to break instead of bend when subjected to great pressure caused the formation of numerous fissures and faults. Most of these fissures were formed parallel to the axis of fold, though many faults also occurred in every direction. As this uplifting and crushing continued great zones in the fold were ground almost to powder. Where the limestone was the weakest or the pressure the greatest the first shattering began, and as these breaks weakened the mass of the rock where they took place, the grinding went on indefinitely until the uplifting force had spent itself.

Influence of eruptive rocks.—Subsequently to the primal folding by which Prospect Mountain was formed eruptions of rhyolite occurred, which had a fur-

ther disturbing effect upon the structure of the country. There are no large outbursts of this rock on Prospect Mountain itself, but it appears as dikes in several places, and large masses of it, and hornblende-andesite, occur in the immediate neighborhood. Many fissures and faults have unquestionably been caused by the eruption of rhyolite, and as it is among the latest disturbing agents which have entered into the formation of the country, it is worthy of attention. It is also extremely probable that the eruption of rhyolite and the solfataric action consequent upon it had an intimate connection with, if they did not actually cause, the deposition of the ore. Although the evidence found in the mines that the rhyolite preceded the deposition of ore is not absolutely conclusive, it is strong enough to make this order of succession almost certain. Where found in the mines the rhyolite is very much decomposed, being in places wholly changed to clay, but still retaining enough of its original characteristics to permit of its determination with certainty. At a distance from the ore bodies this rock, although somewhat weathered, is much fresher.

Relations of the granite to the other formations.—It is not likely that the granite of Mineral Hill, which is the only known occurrence of granite in the district, broke through the quartzite and limestone, but that it originally formed a submarine hill in the bed of the ocean upon which the quartzite, limestone, etc., were laid down, and that its exposure in its present position is due to erosion. Quartzite containing bowlders of a rock which was probably granite has been taken from the bottom of the Richmond shaft, which has attained a depth of 1,230 feet, and is the deepest in the district. These bowlders consist of granular quartz, mica, and a substance that appears to be decomposed feldspar. It has not been possible to determine the nature of this rock with certainty, but it is very probable that it is an altered granite. Such being the case, it would indicate that the body of that rock was at no great distance.

Direction of the dip of the various formations.—The strata of the formations which compose Prospect Mountain do not always dip away from the axial plane of the fold. There is a notable example of this occurrence in the Ruby-Dunderburg mine, which is situated at the head of Goodwin Cañon. The principal shaft is sunk in the Hamburg limestone, but at a depth of 450

VERTICAL SECTION OF PROSPECT MOUNTAIN

Prospect Mt Limestone

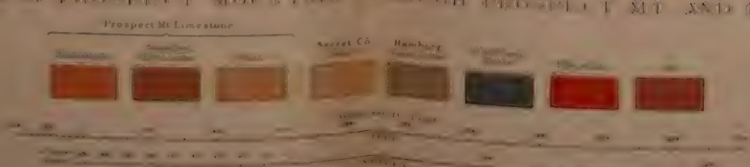
Limestone | Stratified Limestone | Shale | Sec...

UGH PROSPECT MT. AND EUREKA TUNNELS.

burg stone. | Hamburg Shale. | Rhyolite | Ore

Inch. 1200 1400 1600 1800 2000

VERTICAL SECTION OF PROSPECT MOUNTAIN THROUGH PROSPECT MT. AND EUREKA TUNNELS



feet it intersects the Hamburg shale, which in this part of the mountain dips west instead of east, as it should if it followed its normal pitch. At a depth of 800 feet it still dips west, and at an angle much less than it did above, showing that this irregularity, which may be only local however, is more considerable than was to be expected from the nature of the ground, for the reason that the Secret Cañon shale which underlies the Hamburg limestone dips to the east, and if the Hamburg shale should continue its present pitch for some distance further it would come in contact with the Secret Cañon shale and shut out the Hamburg limestone altogether. There is a strong rhyolite dike which cuts through the limestone and shale, pitching to the east, and it is very probable that it is not only connected with the distortion of the strata, but also with the formation of the ore deposits in this mine. Dikes of rhyolite, such as occur in the Ruby-Dunderburg mine, will no doubt be found to exist in many places as mining explorations lay bare the underground formations. As they are rarely but a few feet wide, they may easily lie concealed in the surface débris in those places where there has not been a large overflow of the lava.

Section of Prospect Mountain through Eureka Tunnel.—The underground workings of Prospect Mountain and its spurs, although they have now reached a considerable extent, give by no means a perfect idea of the internal structure of that region, as they expose but a relatively small portion of its rocks. On the east side exposures have been made by the Eureka Tunnel, which has been driven from a point near the head of the west branch of Goodwin Cañon in a nearly due west direction into Prospect Mountain. It is now over 2,000 feet in length, and has passed several hundred feet beyond the ridge of that mountain, below which it attains a depth of about 800 feet. The following are the different formations encountered, in the order of their succession from the mouth of the tunnel:

85 feet mineral limestone[a] (Hamburg limestone).

290 feet shale (Secret Cañon shale).

[a] The name "mineral limestone" has been given by the miners of the district to that limestone in which the ore deposits occur. Although the term "metalliferous" would be more scientifically correct as applied to this rock, the word "mineral" is used not only by miners, but by writers on mining law, and has in practice come to be synonymous with "ore-bearing"; there is abundant precedent, therefore, for the use of the term in this signification.

935 feet mineral limestone (Prospect Mountain limestone).
30 feet shale[a] (Prospect Mountain limestone).
51 feet mineral limestone (Prospect Mountain limestone).
460 feet shale (Prospect Mountain limestone).
90 feet stratified limestone (Prospect Mountain limestone).
50 feet mineral limestone (Prospect Mountain limestone).

The tunnel section, Plate II., gives an excellent idea of the formations which compose the east slope of Prospect Mountain and its spurs. It is true that in all probability no other section parallel to this one, and taken at a considerable distance either north or south of it, would closely correspond, yet it is safe to assume that there would be enough resemblance between them to permit of this particular one being taken as a type. Mr. Hague, in his geological map of the district, has placed the mouth of this tunnel in the Hamburg limestone. The first belt of shale encountered is therefore the Secret Cañon shale.

The second belt of shale is probably nothing more than a fragment of the third and widest, and has been brought into its present position in the tunnel by movements of upheaval. If Plate II. is examined it will be seen that the numerous faults which have occurred along the line of the Eureka Tunnel have so displaced the shale beds that it is not possible to determine with any certainty what was their original position. In drawing this section it has been necessary to depend very much on probabilities in placing the dividing lines between the different formations. The mass of shale marked B, Plate II., does not appear in the tunnel, but it is exposed in the incline winzes of the workings below the tunnel level from a distance 50 feet below that level down to the deepest excavations. As these incline winzes are several hundred feet south of the tunnel, and as the strike of the shale is east of north, it would appear in the tunnel section in the position shown in the plate. There is only one boundary of this shale which has been exposed, namely, that which is laid bare in the winzes, and the other boundaries given it in the section must be necessarily of a very indefinite

[a] The term "Prospect Mountain limestone" of course refers to a group of beds characterized by the presence of certain fossils. Though limestone predominates, the intercalated shales which are characteristic of this formation, according to Mr. Hague, are necessarily classified as members of the same group of beds.

nature. On Ruby Hill there are at least two beds of shale, one of which is intercalated in the Prospect Mountain limestone, and it is certain that at least that number can be found on Prospect Mountain.

Whether the third and widest belt of shale encountered in this tunnel actually comes to the surface or not cannot be determined at present with absolute certainty, but shale rock is found above the Industry mine, and it is probable that it is a part of the third body of shale encountered in the tunnel.

This third belt of shale is also somewhat different in character from the first, which seems closely allied to that found on the surface at Ruby Hill. It consists of alternate strata of argillaceous shale and thin bands of stratified limestone, and, although considerably thicker than the lower shale of Ruby Hill, is lithologically almost identical with it. The width of this shale in the tunnel may be owing to the flatter position which it occupies or to local expansion. The first zone of limestone has the usual appearance of the mineral limestone of the district. It is crushed and broken, and all signs of stratification have been obliterated. It is usually gray in color and sometimes stained yellowish by iron oxide. It contains vuggs and numerous seams. Where not too much crushed, it is crystalline in texture and sometimes brecciated, the different fragments being cemented together by calcite. One of its peculiarities is the difference of the varieties which it presents within a few feet. The foregoing will apply to all the metalliferous limestones of the district. It is difficult to state what the precise differences are which distinguish the mineral limestone from the other limestones. It is not the difference in geological age which distinguishes it, but rather differences which are due to dynamical and chemical action. It is never continuously stratified, and it is never found for any considerable distance without a change in its physical characteristics. It always bears strong evidences of metamorphism. The next zone of limestone is the largest, extending 935 feet from the first to the second belt of shale. It presents the usual characteristics of the mineral limestone, and owing to its great extent offers almost all the varieties of that rock to be seen on any part of the mountain. The narrow belt of mineral limestone found further on is similar to the main mass, from which it is separated by a thin belt of shale.

This thin band of shale most likely was at some time part of the third and widest mass of shale, which lies to the west, and was separated from it by a series of faults; at any rate faults are apparent along its contact with the limestone. Alternating beds of shattered limestone and shale seem to be characteristic of this portion of Prospect Mountain.

At various points along its course the tunnel cuts through seams and fissures which generally cross it at right angles. Their usual pitch is easterly, though there are many exceptions to this rule. The most prominent one of these fissures is at a point 840 feet from the mouth of the tunnel.

Its dip is nearly vertical, perhaps a little inclined to the east. It is open in places and filled with sediment, bowlders, etc., which have been washed in from above. At the point where it is encountered it is about 350 feet below the surface, and it is a characteristic example of numerous occurrences of the same kind, both in the mountain and in Ruby Hill. Like many others, it has been accompanied by ore, which was found on the north side of the tunnel. The principal ore body yet discovered was found about 1,200 feet from the mouth of the tunnel, and was also connected with a fissure which runs a little west of south, but pitches westerly. It did not extend any distance above the tunnel level, but it was followed down about 100 feet, when a very considerable pipe of ore was encountered running under the tunnel in a northerly direction. Most of these fissures and seams are faults produced by the folding and upheaval of Prospect Mountain.

Although there have been local subsidences, it is safe to say that the portions of country which lie west of the fissures upon the foot-wall side have as a rule been raised the highest. The strata have reached their greatest relative height just over the axis of fold. The third belt of shale is overlain by black stratified limestone, which, at its contact with the shale, pitches west at a steep angle until a little distance beyond the summit its stratification is nearly horizontal. West of the stratified limestone the tunnel is in mineral limestone.

The following is a list of specimens from the tunnel, and the points at which they were taken:

430 feet from entrance......Black crushed limestone cemented by calcite, friable.
450 feet from entrance......Grayish crushed limestone, compact granular.

990 feet from entrance	Bluish-black limestone, compact granular.
1,010 feet from entrance	White limestone, compact crystalline.
1,100 feet from entrance	White limestone, compact crystalline, partly calcite.
1,200 feet from entrance	Gray stratified limestone, compact granular.
1,850 feet from entrance	Black limestone, compact granular.
1,900 feet from entrance	Gray stratified limestone, compact granular.
840 feet from entrance	First west cross-cut east side, bluish-gray limestone, compact, brecciated. Sediment from fissure.
1,200 feet from entrance at discovery winze near ore	Yellowish-gray crushed limestone, friable, crystalline.
1,200 feet from entrance	Calcite, stained with manganese.

Section of Prospect Mountain through Prospect Mountain Tunnel.—The Prospect Mountain Tunnel, starting at a point about 2,700 feet west of the summit, nearly opposite the Eureka Tunnel and several hundred feet below it, has been driven 2,350 feet into the mountain. For the first 1,400 feet it passes through a hard compact white limestone, which in places resembles marble. This limestone is not often fissured, but contains some cavities washed out by water. There is nothing about it to indicate that it is mineral limestone. At a distance of 1,400 feet from the entrance a fissure is encountered at nearly right angles, which dips 80° to the west. From this point the character of the limestone changes; it is much more broken, and many of the ordinary varieties of mineral limestone are found, as well as seams crossing the course of the tunnel. At 1,835 feet ore was discovered, but as yet the deposit has not proved valuable. At a little over 2,100 feet stratified limestone was encountered along a fault seam, which dips to the west (see Plate II.). At 2,250 feet shale makes its appearance along a similar seam. The twisting of the stratification of both the stratified limestone and shale indicates that the portions of country east of these two seams were raised relatively to the portion on the west. Although not absolutely certain, it is probable that the shale and stratified limestone encountered in the end of the Prospect Mountain Tunnel is the same body as that encountered in the end of the Eureka Tunnel.

General internal structure of Prospect Mountain.—It will be noticed that the west side of the mountain differs greatly in the formations that compose it from the eastern. This in some measure is owing to the fact that a larger portion of the overlying rocks have been eroded, and that there has not been the same

amount of faulting movement. It is possible also that the western side of this portion of the ridge has not been tilted to the extent that the eastern has, thereby leaving a broader mass of limestone along the line of the tunnel. The quartzite must lie at a very considerable distance below the tunnel, but it is possible that the tunnel will strike it as it is driven to the east.

Distribution of ore in Prospect Mountain.—The largest portion of Prospect Mountain and its adjacent spurs is composed of mineral limestone, and evidence of the number of metalliferous deposits contained in it is offered by the numerous outcrops of gossan, which occur along its whole extent, but which are particularly numerous from Ruby Hill to the Secret Cañon divide. The mines on both sides of the mountain have produced considerable quantities of ore, and there is every reason to believe that this region when properly explored will produce important quantities for years to come. With the exception of some few mines the properties of Prospect Mountain have been but slightly developed. Those, however, that have been opened to any great extent show that there are numerous masses of ore contained in the Hamburg as well as in the Prospect Mountain limestones, and that although no such large bodies as existed in Ruby Hill have been discovered there are many of them. The ore, too, in general is perhaps of a better quality.

CHAPTER IV.

THE STRUCTURE OF RUBY HILL.

Influence of granite on the Ruby Hill formations.—The axis of fold of Ruby Hill, if such a confusedly uplifted mass can be said to have an axis of fold, has a northwest direction from its point of junction with Mineral Hill, as the northern end of Prospect Mountain is called. Mineral Hill is composed in part of an outcrop of granite. The quartzite overlies the granite on its northern side and bends around it to the east and west in the shape of a horseshoe. The limestone touches the granite on the south and overlies the quartzite, separating it on the surface on the east and west sides from the granite. Although the granite does not seem to have broken through the overlying formations, its presence may have had some influence in determining the present position of the quartzite and limestone on this part of the mountain, and from indications observed in the Richmond shaft (see page 12), it is possible that it underlies the quartzite at no very great depth in the Ruby Hill mines. Ruby Hill is separated from Mineral Hill by a narrow divide and a deep ravine which has been eroded in the quartzite. This quartzite is found extending along the southwestern base of the former hill and dips under it to the northeast; that is to say, it pitches northeast at this point. On the east flank of Mineral Hill, on the other hand, the quartzite dips to the east and on the western slope the quartzite also has a westerly pitch. The limestone of Ruby Hill formed one and the same body with that of Mineral Hill before erosion, and it is merely the continuation of the long belt of limestone of which the greater part of Prospect Mountain is composed. The bulk of Ruby Hill is made up of this rock, the shale only making its appearance on the northeastern slope.

Quartz-porphyry eruption.—About a mile and a quarter to the north of Ruby Hill, and beyond Adams Hill proper, there has been an eruption of quartz-porphyry which covers many acres. If this eruption took place at the time of the folding and upheaval to which Prospect Mountain and Ruby Hill owe their origin, it would account for the deflection to the northwest of the different formations found on Ruby Hill. Whether the eruption of this volcanic mass actually caused the bending and twisting before mentioned or not, the fact remains that these formations were so deflected during the upheaval, or subsequent to it, that they lie nearly at right angles to the position they would have occupied had they not been subjected to some other force than that of simple upheaval along their axis of fold. That pressure was exerted from some point to the north of Ruby Hill is clearly proved by the marks of striation observable at various points on the walls of the cross-faults, or those faults which in many places traverse the limestone of Ruby Hill in a northerly or northeasterly direction. These striation marks usually dip to the northeast, which would indicate that the lateral force had been applied from that direction.

Faults.—It cannot be said that all the fault-fissures occurring on Ruby Hill have one general course, but they can be divided into two general systems; the first consisting of those which are approximately parallel to the strike of the formations and which were produced entirely by the folding and upheaval, and the second made up of those which were caused by the same forces supplemented by a strong lateral pressure. These two systems of fissures are mostly to be found in the limestone. To what extent they occur in the quartzite cannot be determined, as the workings in that rock are not very extensive, but it is probable from the nature of that formation that they are not so frequent. There are numerous instances, however, of cross-fissures faulting the quartzite, and this is particularly the case in the Richmond, and will be more fully discussed when the quartzite in that mine is examined. Cross-faults have been noticed in the shale, but they are not so easily detected there, owing to its tendency to bend rather than to break. There are several examples of fissures of the first kind which fault both limestone and shale.

Rhyolite eruption.—There has been another eruption of igneous rock in the neighborhood of Ruby Hill, namely, the rhyolite of Purple Mountain, which is situated about a mile and a half east of the mines, but this eruption could not have caused the deflection of the Ruby Hill formations to the northwest, as it occurred subsequent to the original upheaval, although it was no doubt intimately connected with the subsequent phenomena which accompanied the deposition of the ore.

Extent of the limestone on the surface.—The face of the quartzite mass which overlies the granite dips at an angle of about 40° northeasterly under the limestone of Ruby Hill. The exposure of this belt of limestone on the surface extends over 4,000 feet from the northwest to the southeast. On the northwest end it is covered by the débris of Spring Valley, and on the southeast is cut off by a fault which Mr. Hague has called the "Jackson fault" (Plate I.). This brings it in contact with the Pogonip limestone lying to the east of the Jackson hoisting works. Its width on the surface is from 800 to 2,000 feet. It shows few signs of stratification on the hill itself, and is usually a compact highly crystalline limestone, gray in color and much weathered.

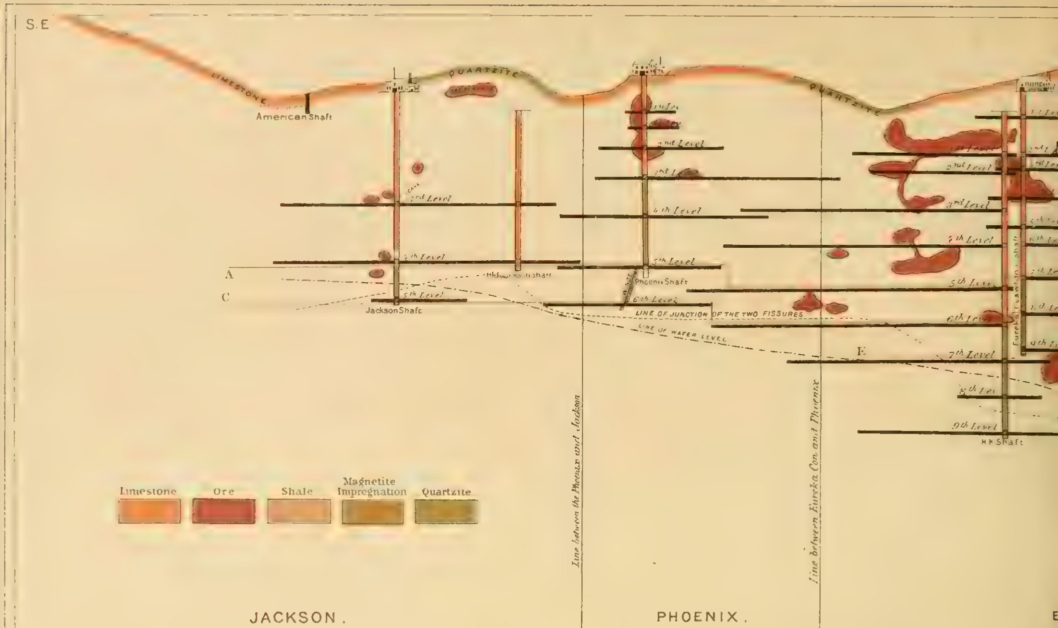
Extent of the shale on the surface.—Beginning at the northwest, the shale first makes its appearance at the Albion mine, follows round a promontory of limestone, which extends nearly 1,000 feet to the north, and narrows down to a point in the lower part of the town of Ruby Hill before reaching the fault to the east. The shape of this shale body is very irregular; it is widest to the north of the Richmond hoisting works, where it attains a width of 2,400 feet, and narrowest, except where it comes to a point, north of the above-mentioned promontory. Its course is nearly east and west, and its dip northerly. The angle of dip of its stratification varies greatly. It sometimes reaches 45°, but is frequently as small as 25°.

Dip of the three formations.—It may be as well to state here that nowhere on Ruby Hill does the dip of the stratification of any of the three formations, quartzite, limestone, and shale, correspond with the dip of their planes of contact. In other words, the strata of these three formations do not conform to each other in their present position in the mines, though no doubt they were originally laid down conformably. This lack of parallelism is

peculiar to the region of Ruby Hill[a] and Prospect Mountain, and is due to faults which in many places have followed the contact of the different formations. The local non-conformity bears upon the ore bodies only as an indication of structure.

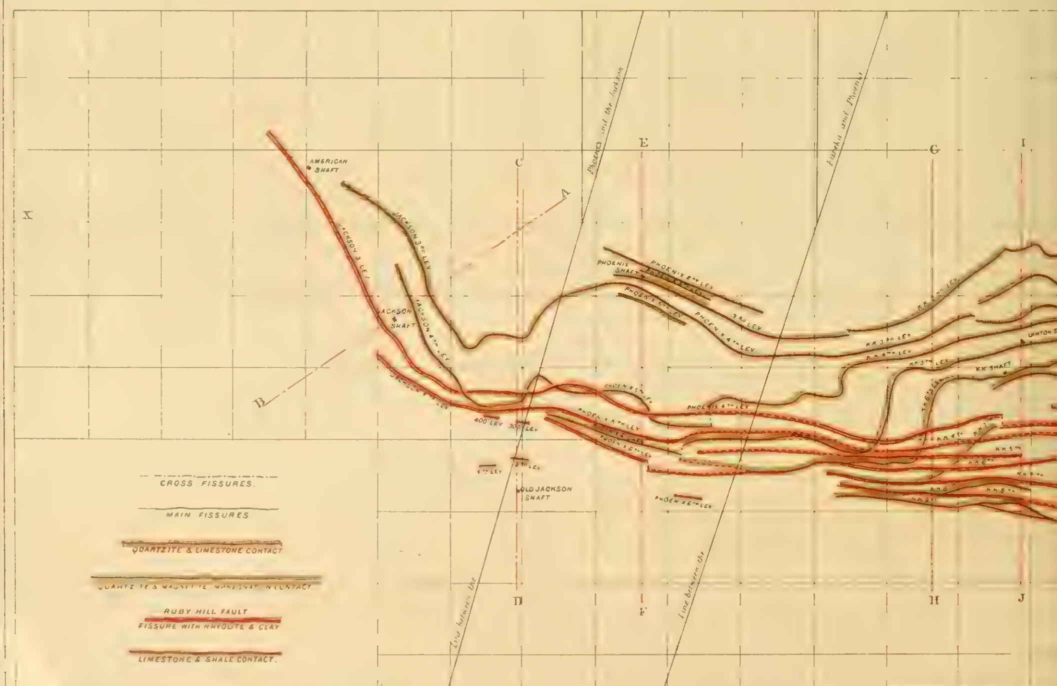
Relations of the three formations underground.—The subterranean structure of Ruby Hill presents features of unusual interest to the geologist and miner. The underground explorations have been very extensive, but they have not been so complete that it has been possible to trace the contacts of the different rocks in every instance, and in making the maps which accompany this memoir it has often been necessary to calculate the position of points not actually exposed. These calculations have been made with care and due reference to the position which the different formations bear to each other at all exposed points. The main beds of Ruby Hill are an underlying mass of quartzite, a broad zone of mineral limestone, and an overlying belt of shale, all of which have been tilted so that they stand at an angle of about 40°; this angle being somewhat greater in the upper than in the lower workings of the mines. That these strata should pitch at a smaller angle as they approach the valley is naturally to be expected. Beginning at the Jackson mine, the most southerly location on the mineral zone, the strike of these formations is to the north, but their course is soon deflected toward the west, until, in the Albion mine, the most northerly, they strike nearly east and west. Their course underground resembles in its general outlines that on the surface, though there are many irregularities and frequent breaks caused by faults. As far as the deepest workings have penetrated (namely, to a depth of 1,230 feet in the Richmond shaft), the average dip of the contact of the quartzite and limestone has been found to be about 40°. Near the surface the angle of dip is much less, as the highest point of the quartzite seems to be at the crest of an anticlinal fold. The line of contact between quartzite and limestone on the southwest slope of Ruby Hill would be very near the top of this anticlinal, which can be ob-

[a] It should be mentioned that Ruby Hill proper stops at the divide south of the Eureka hoisting works, and that the Jackson and Phœnix mines are on spurs of Prospect Mountain. The term "Ruby Hill mines," however, will be used in this report as including the Jackson, Phœnix, K. K. (now belonging to the Eureka Company), Eureka, Richmond, and Albion, the six mines that are situated on that belt of limestone included between the quartzite and shale.



ELEVATION ON PLANE THR

Scal

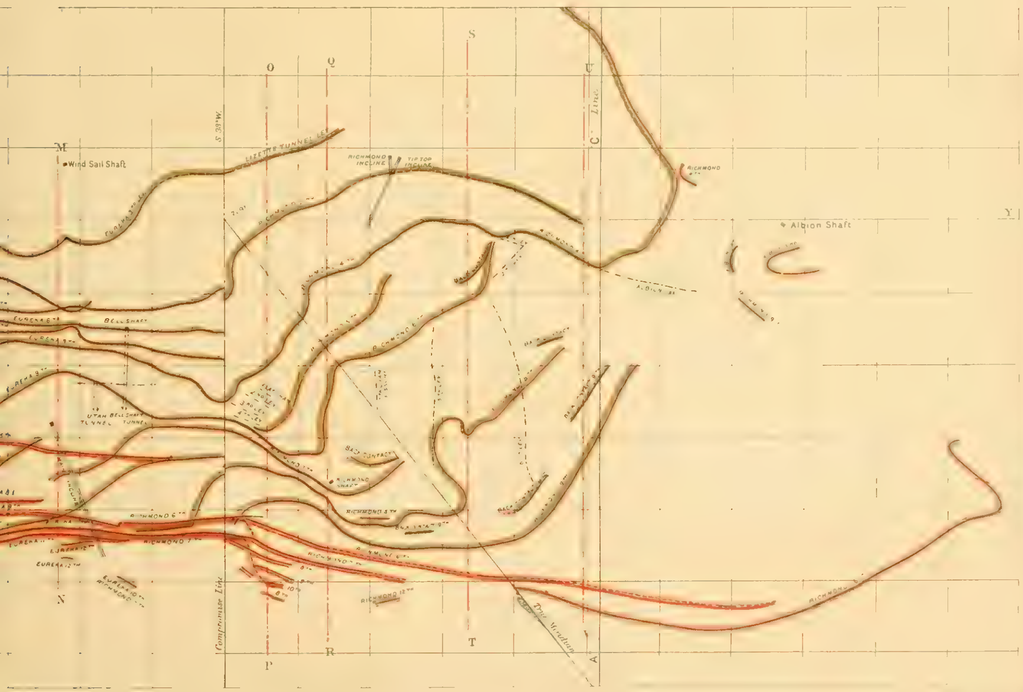


Mapping by N. Wescoatt, del

PLAN OF THE UNDERGROUND CONTACTS C

Y OF RUBY HILL MINES

ach



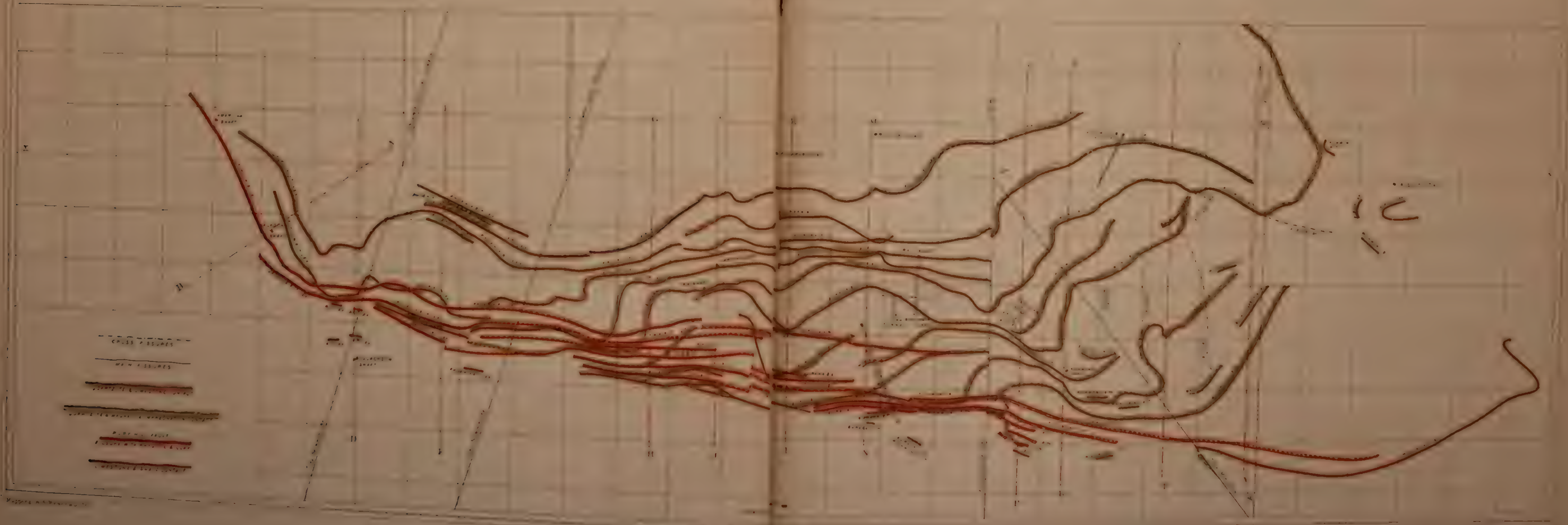
J.S.Curtis Geologist

DIFFERENT FORMATIONS OF RUBY HILL

1200 1400 1600 1800 2000

200 400

ELEVATION ON PLANE THROUGH X.Y. OF RUBY HILL MINES



PLAN OF THE UNDERGROUND CONTACTS OF THE DIFFERENT FORMATIONS OF RUBY HILL

served in a tunnel which is run into the southwest side of Ruby Hill some few hundred feet to the northeast of the Isandula shaft, a shaft sunk in the débris of Spring Valley. In this tunnel the quartzite is cut through, and there are signs of a flat undulation; the strata dipping to the northeast in the face of the tunnel and to the southwest at its entrance. There is said to be another locality where this can be observed, but it was not possible to examine it, as the drift in which it occurs was inaccessible. It is in a drift run to the west from the Buckeye shaft, and 30 feet below the first level (Lawton tunnel) of the Eureka mine. The position of the quartzite can be seen on vertical cross-section No. 6, Plate VII.

The quartzite and limestone contact.—There is no regularity about the dip of the quartzite and limestone contact, and there are but few places along its surface where a cross-section would show that the dip remained constant for any considerable distance. A glance at the various vertical cross-sections and the plan of underground contacts (Plate III.) will show that both the dip and the strike of the quartzite contact are very irregular. In some places, though these are not frequent, this contact pitches back. This can be observed on the plan of contacts (Plate III.), where the quartzite on the fourth level of the Eureka projects out over that found below on the fifth. It also pitches back at the end of a drift from the big cave situated nearly on a level with the little tenth level of the same mine. This cave, which will afterwards be described, lies west of the main incline from the ninth level. Besides smaller irregularities in the quartzite, there are three large protrusions along the course of this contact, which occur, respectively, in the Phœnix, K. K., and Richmond mines. The first of these occurs in the Phœnix and K. K. ground and extends from above the fourth level down to the seventh of the latter mine with a northerly trend. The second begins about 300 feet southwest of the Lawton or Eureka shaft on the third level and extends with a northeasterly trend down to the tenth level. The third begins on the surface near the "compromise line"[a] and trends in a northerly direction down to the ninth level of the Richmond, where it disappears. Along the line of dip of this same contact there is a great depression sev-

[a] The "compromise line" is the line dividing the respective claims of the Richmond and Eureka companies, and was established during the early litigation between those mines.

eral hundred feet in vertical extent, which occurs at about the same depth in all the mines, and which, combined with the undulations along the line of strike, forms large basins of an oval shape. These basins are intimately connected with the ore bodies and will be referred to later.

The main fault.—The contact surface between the limestone and the shale, like that between the quartzite and limestone, is very irregular, but there seems to be little similarity between them, owing to the presence of a fault. This fault, to which the name Ruby Hill fault has been given, has had a very important bearing upon the structure of the mineral zone as well as upon the ore deposits themselves. Beginning at the southeast, it is first to be observed at the American shaft, which is about 25 feet deep, and is situated a few hundred feet south of the Jackson hoisting works. The course of the fault from this point is a little west of north, and, although not perceptible on the surface, passes west of the Jackson hoisting works, and can be seen in the workings of that mine as well as in a tunnel near the Phœnix line. From this shaft it changes its course to the northwest, and were it not for the débris could no doubt be seen northeast of the Phœnix shaft. It passes northeast of the Eureka and K. K. shafts, but must be very close to the latter, and is plainly visible near the mouth of a tunnel run southwesterly to connect with the Bell shaft. The last place where it can be observed on the surface is near the Richmond office. Although this fault is not continuously traceable above ground, owing to the débris, its existence is fully established by the fact that it is encountered at numerous points in the underground workings of all the mines of Ruby Hill.

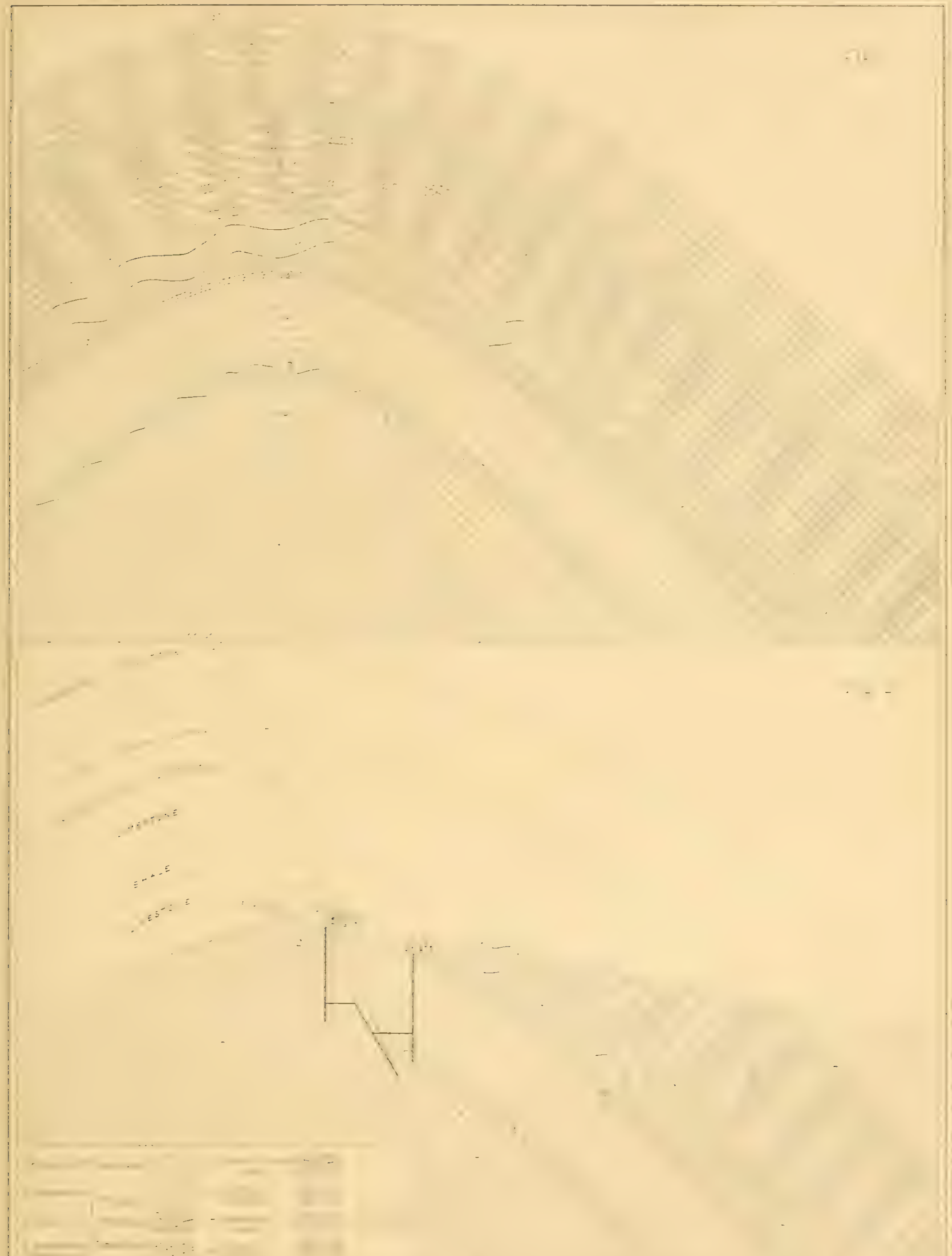
Dip and strike of the main fault.—The average dip of the plane of this fault is about 70° northeasterly, and it is of remarkable uniformity, scarcely ever varying 5° one way or the other. Its course also is extremely direct, with the exception of the bend between the Phœnix and Jackson. This fault is marked by the presence of a fissure filled with clay, which is widest in the Jackson and Phœnix mines, where in places it measures as much as 15 feet.

The filling of the fissure.—The filling or material contained in this fissure is very different at different points along its course, although there is not much change in it where it is followed along its line of dip.

In the Jackson and Phœnix mines it is rhyolite, which is usually much decomposed, but owing to the mica and smoky quartz which it contains is still easily recognizable. At a place somewhere between the last point at which it is seen in the Phœnix, and the first where it is encountered in the K. K., positive evidences of its rhyolitic character are lost. It is likely that the change is gradual, as there is something over a hundred feet of unexplored ground between where the rhyolite is last seen on the sixth level of the Phœnix and the first place where it is encountered on the sixth level of the K. K. It is possible, however, that this change may take place suddenly. Where the fissure is found in the K. K. and Eureka mines, the filling is of a dull yellow, bluish, or occasionally white color, whereas in the before-mentioned localities it was uniformly white, except where stained by its contact with ore. In following the fissure northwest it becomes narrower, until in the Richmond mine it is only a few inches wide, although it is a distinct and well-defined seam, with a different character of limestone on either side of it. The clay has here lost its plastic nature and is a calcareous product of the attrition of the two walls. Underground, as well as on the surface, this fissure takes a northwest course, after leaving the Jackson, which it retains until it is last seen in the Albion ground.

General features of the main fissure.—This fissure will hereafter be called the Ruby Hill fault or main fissure, as to its formation are due the most important features of the present structure of Ruby Hill, as well as the relations of the ore bodies to each other. A careful description of its manner of occurrence and of the phenomena attending it is necessary for a complete understanding of the deposits of Ruby Hill; and although when examined in one particular locality it does not seem to be of remarkable importance, taken throughout its entire course it is found to be the key to the solution of the structural problem of the mineral zone. A proof of its comparatively recent formation is the fact that it faults all the formations with which it comes in contact, but is itself nowhere faulted or dislocated. At various points in the lower levels of all the mines southeast of the compromise line shale is encountered on the northeast or hanging wall side of this fissure. This body of shale, however, nowhere reaches the surface, as it is cut off by the fault. As the workings in this shale are inconsiderable, it is impossible to tell what

may be its angle of dip, but it is apparently less than 45°, and the shale pitches to the northeast away from the fissure. As this formation will be described at length hereafter, it is only necessary to mention it here in reference to the fault. It is evident that the country southwest or on the foot-wall side of this fissure has been raised many hundred feet relatively to the hanging wall. Whether the former was raised or the latter subsided is immaterial, as the same effect would be produced in either case. It is probable, however, that there was both subsidence and upheaval, but that the latter exceeded the former. In the Eureka mine the distance to which the southwest wall has been raised relatively to the northeast wall is over 1,400 feet. The faulting action is represented in Plate IV. Fig. 1 is an ideal section of the country through the junction of the Locan shaft cross-cut and the twelfth level of the Eureka mine, on a line at right angles to the strike of the fault which is represented by the line X Y. The order of succession of the formations, beginning at the lowest, is: Prospect Mountain quartzite; Prospect Mountain limestone, consisting of two beds of limestone, with an intercalated bed of shale; Secret Cañon shale; Hamburg limestone; Hamburg shale; Pogonip limestone. Fig. 2 represents the position of the different formations after the faulting and uplifting of the foot wall, and after the erosion of the overlying formations had given the country its present configuration. It will be noticed that the intercalated belt of shale to the southwest of the fissure has been eroded as well as the upper stratum of Prospect Mountain limestone. In the Eureka mine the lower shale is not found much above the little tenth level (830 feet below the top of the Lawton shaft), but in the Jackson it appears above the third level (315 feet below the top of the Jackson shaft). In the Richmond mine it is exposed from the surface down to nearly the deepest workings, but as the shale in the Richmond is of a complicated structure its discussion will be postponed until the shale itself is examined. One of the remarkable features of this widely extended Ruby Hill fault, which runs in an unbroken line from beyond the Jackson to the Albion, is its extreme regularity when compared with the contact planes of the three formations, quartzite, limestone, and shale. In breaking through these formations it seems to have been but little influenced by the difference in their cohesion. In the Richmond mine, crushed limestone occupies the



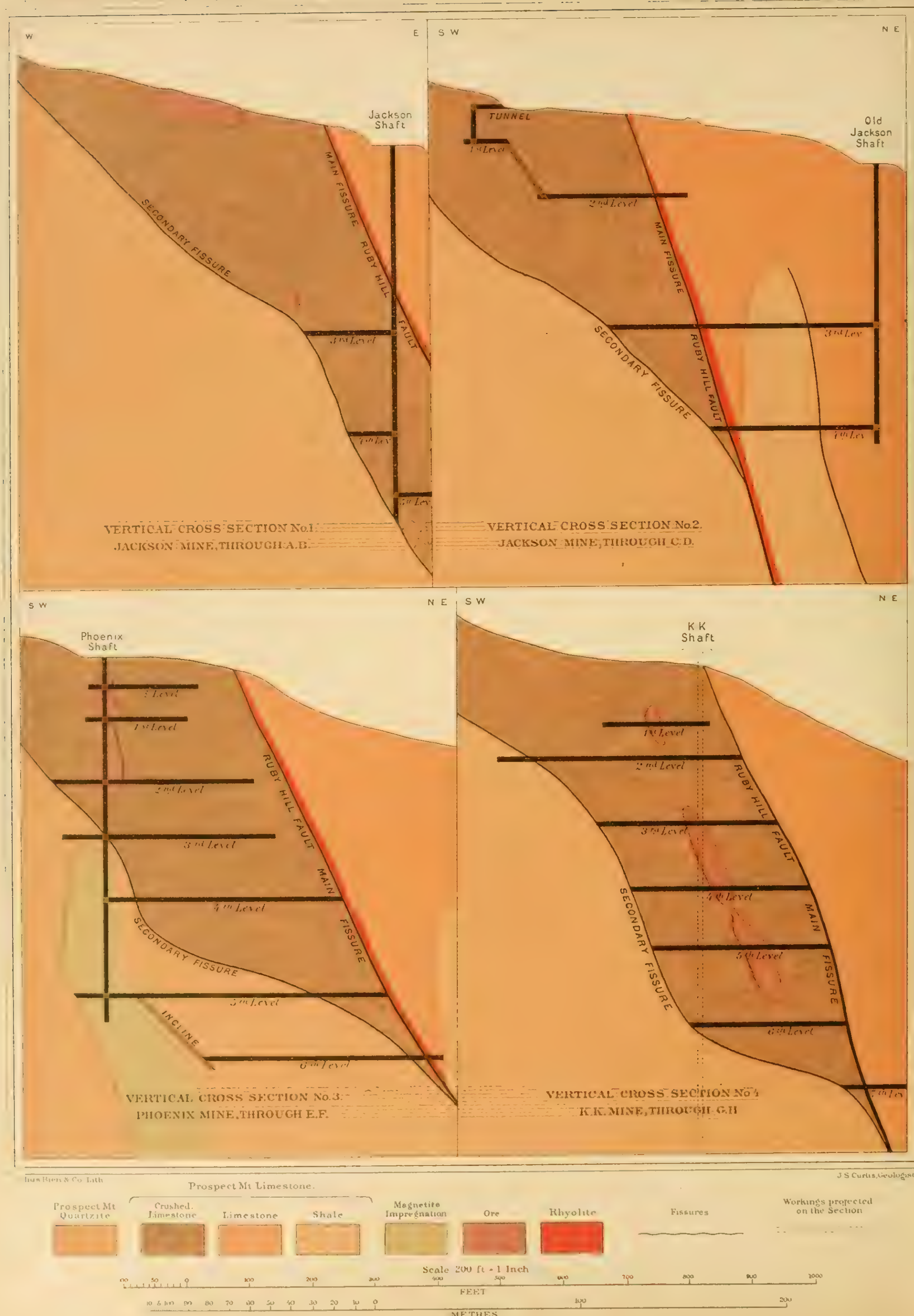
IDEAL SECTION OF RUBY HILL

foot-wall side of the fissure and shale the hanging wall above the fifth level. Below that level stratified limestone intervenes between the fissure and the shale. In this mine the fissure is generally filled with a hard black clay, and is often not more than an inch wide. It might be mistaken for an ordinary slip, were it not for the differences in character everywhere exhibited by the rocks on each side of it. Splices or small slips are of frequent occurrence in connection with it, as is often the case with such fissures. In this mine it appears at first sight to be of little importance, and has been overlooked almost entirely by the engineers who have examined the underground workings. When, however, it is taken in connection with its extension through all the mines to the southeast, and with the fact that it is a fault plane along which the whole southwestern country has been raised from 500 to 2,000 feet, it becomes of great importance as regards the structure of Ruby Hill.

Detailed description of the main fissure.—It will be seen on examining the plan of contacts (Plate III.) and the various horizontal sections (Plates XIII. and XIV.) of the different mines that there are a number of places on the various levels where the distance between the points at which the fissure has been laid bare is very considerable. The usual method of prospecting in the mines southeast of the Richmond has been to run a main level along the line of contact between quartzite and limestone, sometimes cutting through the quartzite where its projections into the limestone are so great that the length of the drift would be materially increased if this contact were followed; and then if ore was not encountered along this line, to seek for it by driving numerous cross-cuts towards what was supposed to be the shale, but was in reality the Ruby Hill fault. Sometimes it was found to be more convenient to keep the principal drift entirely in limestone and cross-cut in opposite directions from it. Often these cross-drifts did not reach either the quartzite or main fissure, though the mine superintendents were usually more particular about a thorough exploration of the quartzite contact than they were about the fissure. Drifts along this fissure were uncommon, except in the lower levels, where the quartzite and fissure came together. Owing to this method of prospecting, the plane of the fissure was not as well explored as was that of the contact of quartzite and limestone. There can be no rea-

sonable doubt, however, that the fissure, which in the Jackson and Phœnix carries rhyolite, is identical with that which in the K. K. and the Eureka carries calcareous clay. The fissure is intersected by drifts in over twenty places, all of which correspond in position with that which the fissure would be supposed to occupy from an examination of the exposures taken singly. Better proof than this of the identity of a surface is rarely met with in mines. When there are many fissures or slips it is not always an easy matter to distinguish one from the other, for one may have given out and another one taken its place, or faults might have occurred which would bring another fissure into the place where the first was to have been expected. This could not be the case in the present instance, as there is no strong fissure within several hundred feet at any rate of the one in question. This is shown by the explorations which have been carried on in the "front limestone" on the sixth level of the K. K. and in the cross-cut to the Locan shaft in the Eureka mines. So, too, the contact of an irregular surface, like the contact of quartzite and limestone, requires more proof than that of a regular one. In the present case the evidence is amply sufficient not only to prove the continuity of the fissure, but its unusual regularity. If the change in the material composing the filling of the fissure had occurred at the single bend of any importance in this fissure, which appears in the Jackson, a drift along its course might have been necessary to establish the identity of the two branches. The rhyolite, however, gives out between the workings of the Phœnix and K. K., and to the northwest of this point is replaced by clay identical with that which fills the fissure in the Eureka and K. K., so that the disappearance of the rhyolite forms no argument against the continuity of the fissure. This clay also, as found in the Eureka and K. K., is partly derived from the rhyolite, and is merely the decomposed feldspar of that rock mixed with crushed limestone.

The main fissure at the American shaft.—The first point where the main fissure is noticeable at the southeast end of the Ruby Hill fault is at the American shaft, which is situated over 400 feet south of the Jackson hoisting works. The shaft, which is 25 feet deep, is sunk in Pogonip limestone. From near the bottom of this shaft a cross-cut has been driven to the quartzite in a southwesterly direction. In this cross-cut, 16 feet from the shaft, the main


W
E
Jackson Shaft
MAIN FISSURE
RUBY HILL FAULT
SECONDARY FISSURE
3rd Level
4th Lev
5th Lev
VERTICAL CROSS SECTION No.1.
JACKSON MINE, THROUGH A.B.
S W
N E
TUNNEL
1st Level
2nd Level
Old Jackson Shaft
MAIN FISSURE
RUBY HILL FAULT
SECONDARY FISSURE
3rd Lev
4th Lev
VERTICAL CROSS SECTION No.2.
JACKSON MINE, THROUGH C.D.
S W
N E
Phoenix Shaft
1st Level
2nd Level
3rd Level
4th Level
5th Level
6th Level
RUBY HILL FAULT
MAIN FISSURE
SECONDARY FISSURE
INCLINE
VERTICAL CROSS SECTION No.3.
PHOENIX MINE, THROUGH E.F.
S W
N E
K K Shaft
1st Level
2nd Level
3rd Level
4th Level
5th Level
6th Level
7th Lev
RUBY HILL FAULT
MAIN FISSURE
SECONDARY FISSURE
VERTICAL CROSS SECTION No.4.
K.K. MINE, THROUGH G.H.
Julius Bien & Co. Lith.
J S Curtis, Geologist
Prospect Mt Limestone.
Prospect Mt Quartzite
Crushed Limestone
Limestone
Shale
Magnetite Impregnation
Ore
Rhyolite
Fissures
Workings projected on the Section
Scale 200 ft = 1 Inch
FEET
METRES

fissure, containing decomposed rhyolite, is encountered. On the west side of the fissure, which pitches easterly, interstratified limestone and shale are found, the strata of limestone becoming less numerous as the quartzite is approached. These beds continue for a distance of 134 feet and to within 10 feet of the quartzite, this interval being occupied by crushed Prospect Mountain limestone.

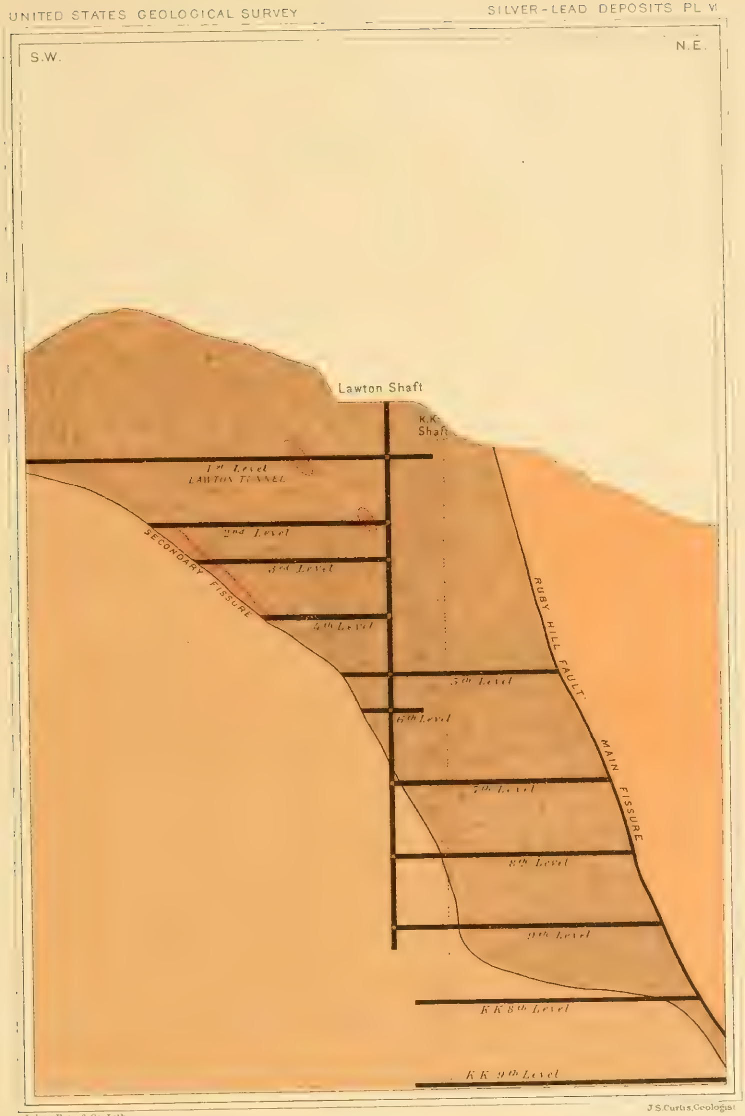
The main fissure in the Jackson.—The fissure containing rhyolite is also found in the Jackson tunnel. In proceeding downward it is next to be found on the third level of the Jackson mine, though it may possibly make its appearance in some of the abandoned workings which are now inaccessible. It crosses the new Jackson shaft somewhere above the third level and continues with its usual dip and strike down to the fourth and fifth. It appears at numerous points on all these levels and is invariably filled with rhyolite, which is more or less decomposed. It is 150 feet from the quartzite on the third level in the cross-cut to the old Jackson shaft, is about 15 feet from it on the fourth, and comes in contact with it somewhere between the fourth and fifth. It is 60 feet west of the shale on the third, and lies on the foot-wall side of it on the fourth, in the before-mentioned cross-cut.

The main fissure in the Phœnix.—In the Phœnix the main fissure, still filled with rhyolite, is first noticed on the fourth level and continues with its accustomed pitch and strike down to the deepest workings on the seventh level. It is over 200 feet removed from the quartzite on the fourth, but comes in contact with it about 40 feet below the fifth near the Jackson line. On the sixth level, farther to the northwest, it is but a few feet from the quartzite at the end of the cross-cut from the main incline. It may be as well to state here that the depth at which the main fissure comes in contact with the quartzite increases as the fissure is followed westward. Three hundred feet farther to the northwest, on this same level, it is 50 feet southwest of a body of shale, probably the same which is encountered in the Jackson. On the seventh level it is almost everywhere in contact with the quartzite, and is also in all likelihood in close proximity to the shale.

Main fissure in the K. K.—The fissure is first encountered in the K. K. mine on the third level and dips at its usual angle down to the deepest workings on the ninth level. On the third it lies over 250 feet northeast of the quartz-

ite, and on the sixth it comes in contact with it. In the southeastern part of the K. K. ground the quartzite face follows the course of the fissure, but as the Eureka line is approached the quartzite bends westward. In the lower levels the quartzite and the fissure are together for nearly the whole of their extent, and the limestone is shut out from between them.

Main fissure in the Eureka.—In the Eureka mine the Ruby Hill fault can be noticed near the surface in the Bell shaft tunnel. This tunnel has been driven in a southwesterly direction from a point 300 feet distant from the compromise line to connect with the Bell shaft, and cuts through the fissure about 50 feet from the mouth. The fissure can also be found in the Utah tunnel near by, and is encountered in one or two other places, but it is not an easy matter to trace it on the surface, as the seam is small and usually covered with débris. At the surface it is about 700 feet from the quartzite. It is not again met with in the workings of the Eureka mine until it is encountered in several cross-cuts on the fifth level. Its dip and strike between these levels seem to be normal and to conform with the dip and strike in all other parts of the mine. It is first found in contact with the quartzite on the twelfth level, 1,030 feet below the top of the Lawton shaft. Near the K. K. line the junction takes place somewhat above the twelfth level. In the cross-cut to the Locan shaft, 12 feet above the twelfth level, the fissure which lies between quartzite and shale is very narrow, but contains a foot or so of ore. As this level is followed toward the compromise line the quartzite bends around towards the west, a block of limestone intervening between it and the fissure. The fissure comes in contact with the shale nearly as high up as the ninth level, but the developments made at this point are not sufficient to determine at exactly what point the junction takes place. On the little tenth (60 feet above the tenth), tenth, and eleventh levels the main fissure lies under the foot-wall or southwestern side of the shale as the compromise line is approached. At or near this line on all these levels the shale bends to the northeast, but the fissure continues its usual course. Its character in this region can be best observed on the tenth level of the Eureka and the seventh of the Richmond two corresponding levels. While in contact with the shale the usual clay filling of the fissure is much thicker and stained



Julius Bien & Co. Lith. J.S. Curtis, Geologist

VERTICAL CROSS SECTION Nº 5, EUREKA MINE, THROUGH I.J.

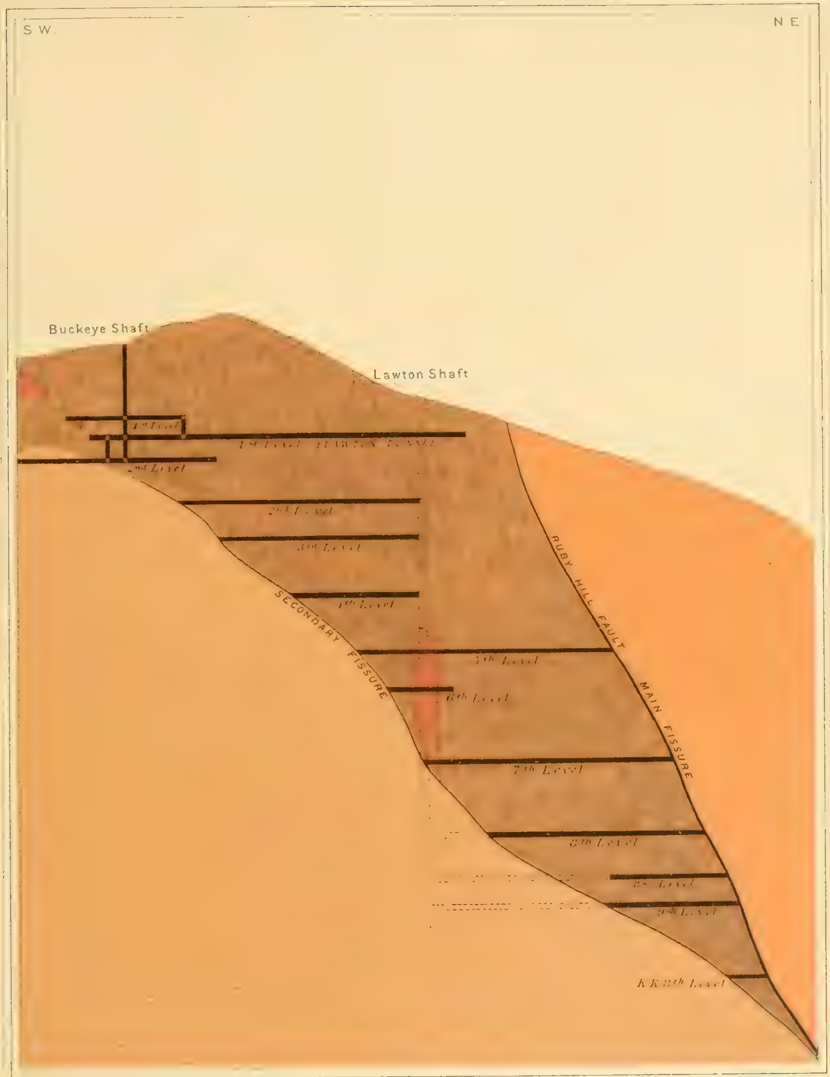
Prospect Mt. Limestone

Prospect Mt. Quartzite | Crushed Limestone | Limestone | Ore | Fissures with Clay | Workings projected on the Section.

Scale 200 ft = 1 Inch

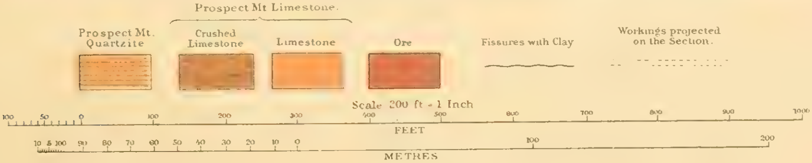
FEET

METRES

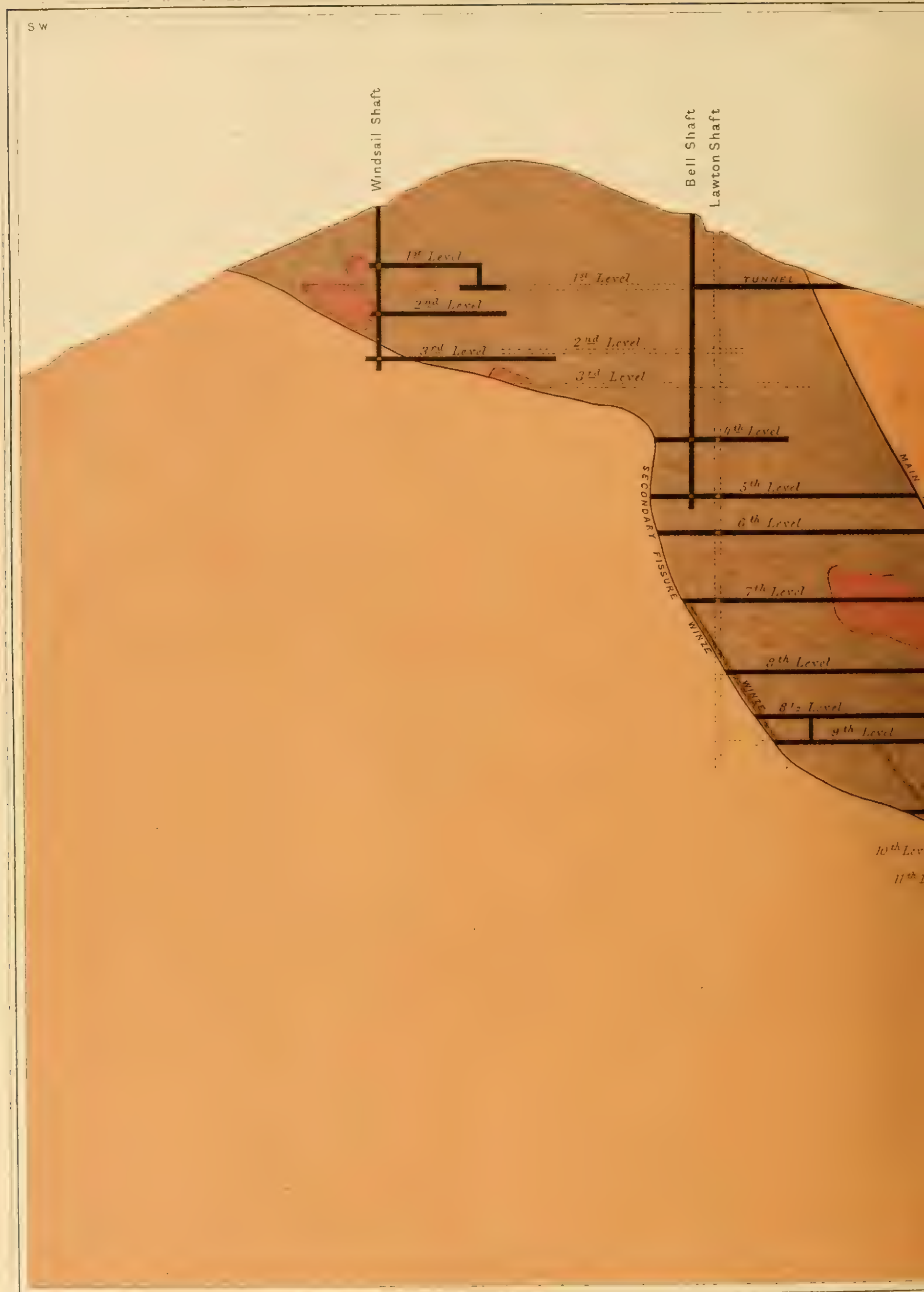


Julius Bien & Co. Lith J S Curtis Geologist

VERTICAL CROSS SECTION Nº 6, EUREKA MINE, THROUGH K.L.



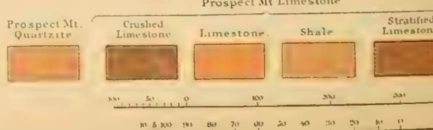
8

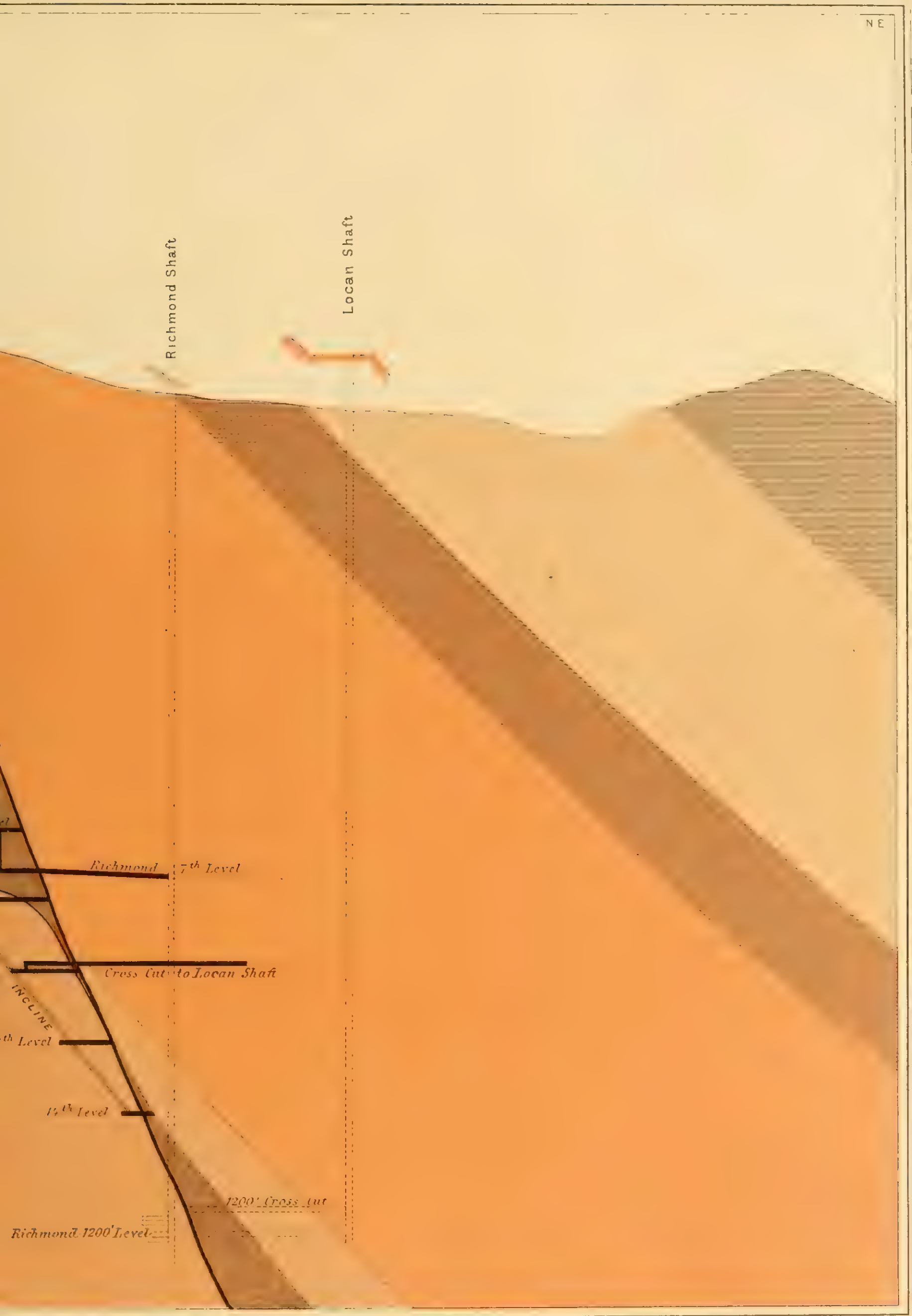


Julius Bien & Co. Lith.

VERTICAL CROSS SECTIO

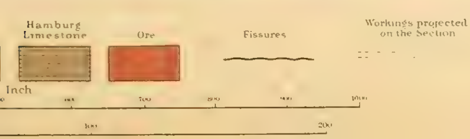
Prospect Mt Limestone



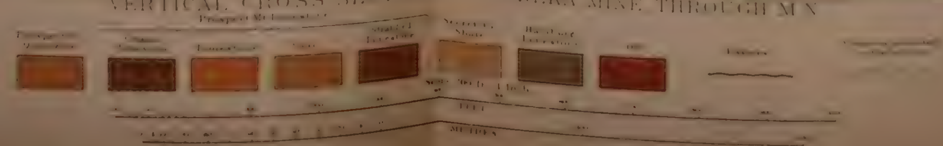


UREKA MINE, THROUGH M.N.

J S Curtis Geologist



VERTICAL CROSS SECTION No 7 EUREKA MINE THROUGH M N



slightly yellow. Much of this clay is derived from the shale by attrition and the decomposing action of waters passing along the fissure.

Main fissure in the Richmond.—The fissure leaves the shale at a short cross-cut in the Richmond ground just after the compromise line is passed, and is here very narrow, although it is plainly defined, and contains from a few inches to a foot of clay. It continues its normal course, and is distinctly visible, with its filling of clay, along the northwest drift in the southeastern portion of the Richmond seventh level. After leaving the shale the space between the latter and the fault is occupied by stratified limestone, while the rock lying on the southwest of it consists of the usual broken and highly metamorphosed limestone. On the surface this fissure can be seen near the Richmond office. On the first level of this mine it is in contact with the shale, 94 feet west of the Richmond shaft. On the second level it is 35 feet west of the shaft, and is also in contact with the shale, and remains so down to the fourth, where it is somewhat split up, and exhibits a tendency to leave the shale. On the fifth level the fissure is found

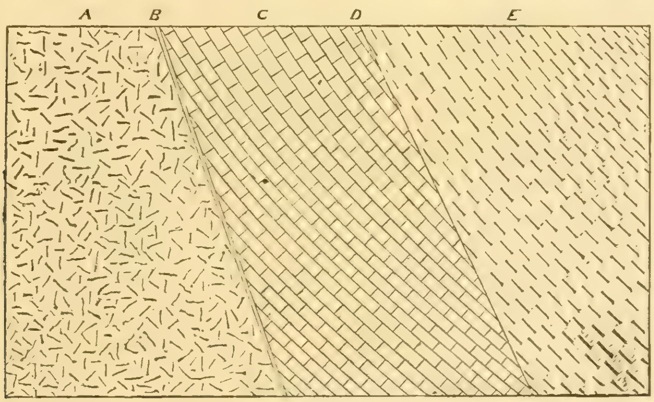
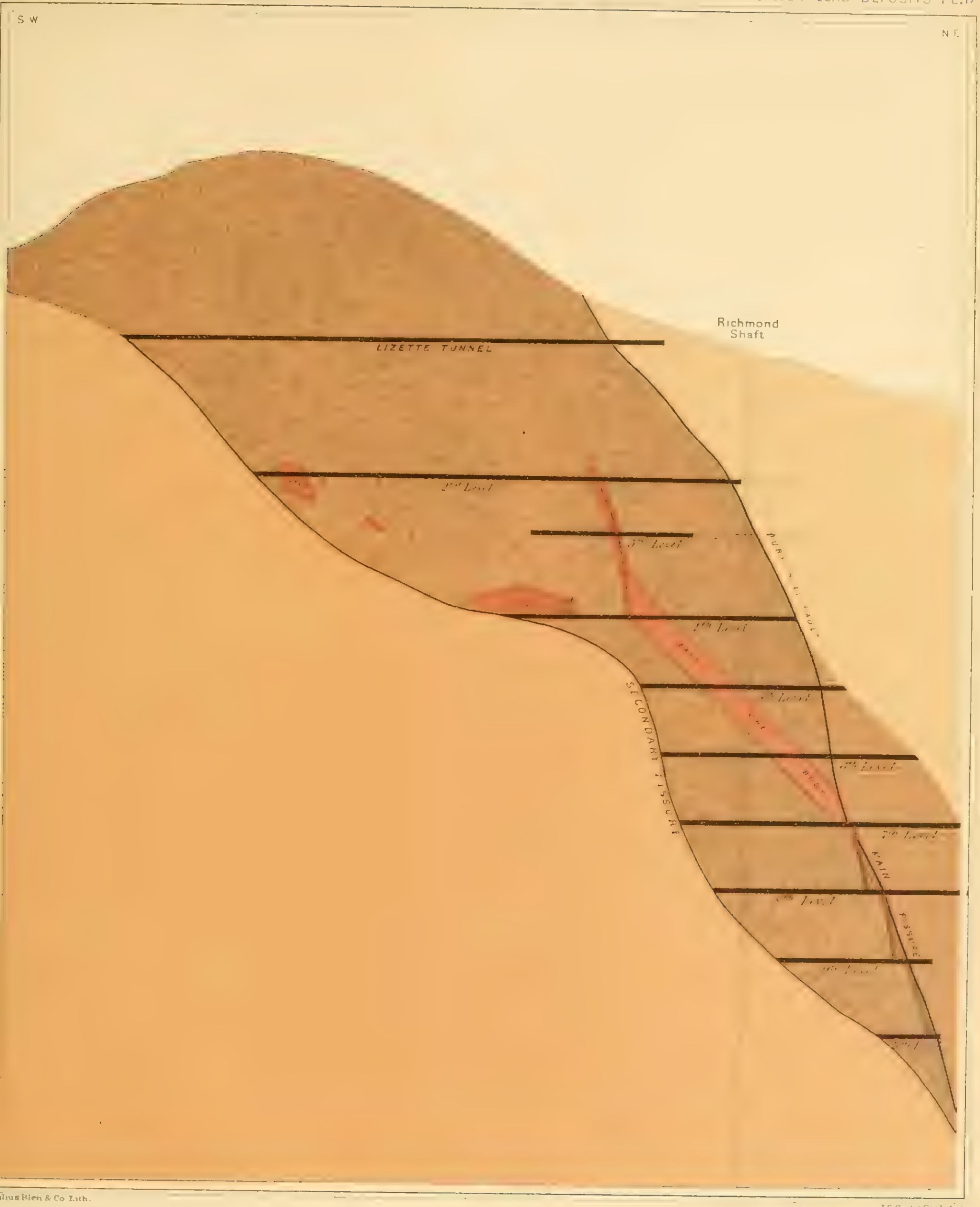


FIG. 1.—Relation of formations to main fissure.
A. crushed limestone. B. main fissure. C. stratified limestone. D. contact of stratified limestone and shale. E. shale.

in the first north cross-cut 182 feet from the main drift. Between it and the shale the stratified limestone, which is here 30 feet wide, can be first definitely distinguished. This band of limestone, which increases in width as depth is attained, is always found on the hanging-wall side of the fissure,

between it and the shale below the fifth level. On the ninth it has been cross-cut for over 100 feet without the shale being encountered. The diagram, Fig. 1, represents the relative positions of the mineral-bearing limestone, fissure, stratified limestone, and shale, as they are developed by a cross-cut. The fissure is not often wide, but it exhibits unmistakable signs of a great upward movement of the country to the southwest of it. In places there are vertical striations, and the hard stratified limestone which forms its hanging wall is often polished as smooth as glass. The strata immediately adjoining the fissure are nearly parallel with it, but as they approach the shale their angle of dip becomes less until it is frequently as small as 20°. The contact of the stratified limestone and shale is very irregular, the strata of the two formations being intermingled, so that there is no well-defined line of demarkation between the two. This contact, as far as can be determined by the examination of the limited portion exposed in a drift, has less dip than the main fissure, but the dip of the bedding-planes of the shale conform very nearly to those of the limestone. The curvature of the planes of bedding in limestone and shale shows the upward motion of the southwest country. The upper portion of the Prospect Mountain limestone which underlay the shale retained its stratification, and is now found to the northeast of the fissure, while the lower portion was forced upward to the southwest of the fissure, its stratification being for the most part obliterated by the crushing accompanying its translocation. This stratified limestone is of dark color, and is similar in character to that composing a large block which at the uplifting of the southwest country was left in a comparatively undisturbed condition. This rock can be observed on the sixth level of the Richmond, near the A. C. line (the dividing line between the Richmond and Albion mines), in the widest part of the mineral belt.

The places where cross-cuts have been driven up to the shale are not as numerous as could be wished, but there are enough of them to establish the general relative position of the fissure and shale, and it cannot be reasonably doubted that the fault is continuous between the points where it has been laid bare. This fissure has very nearly the same dip and strike that it had in the mines to the southeast. It extends through the Richmond



Julius Bien & Co. Lith. J. S. Curtis, Geologist

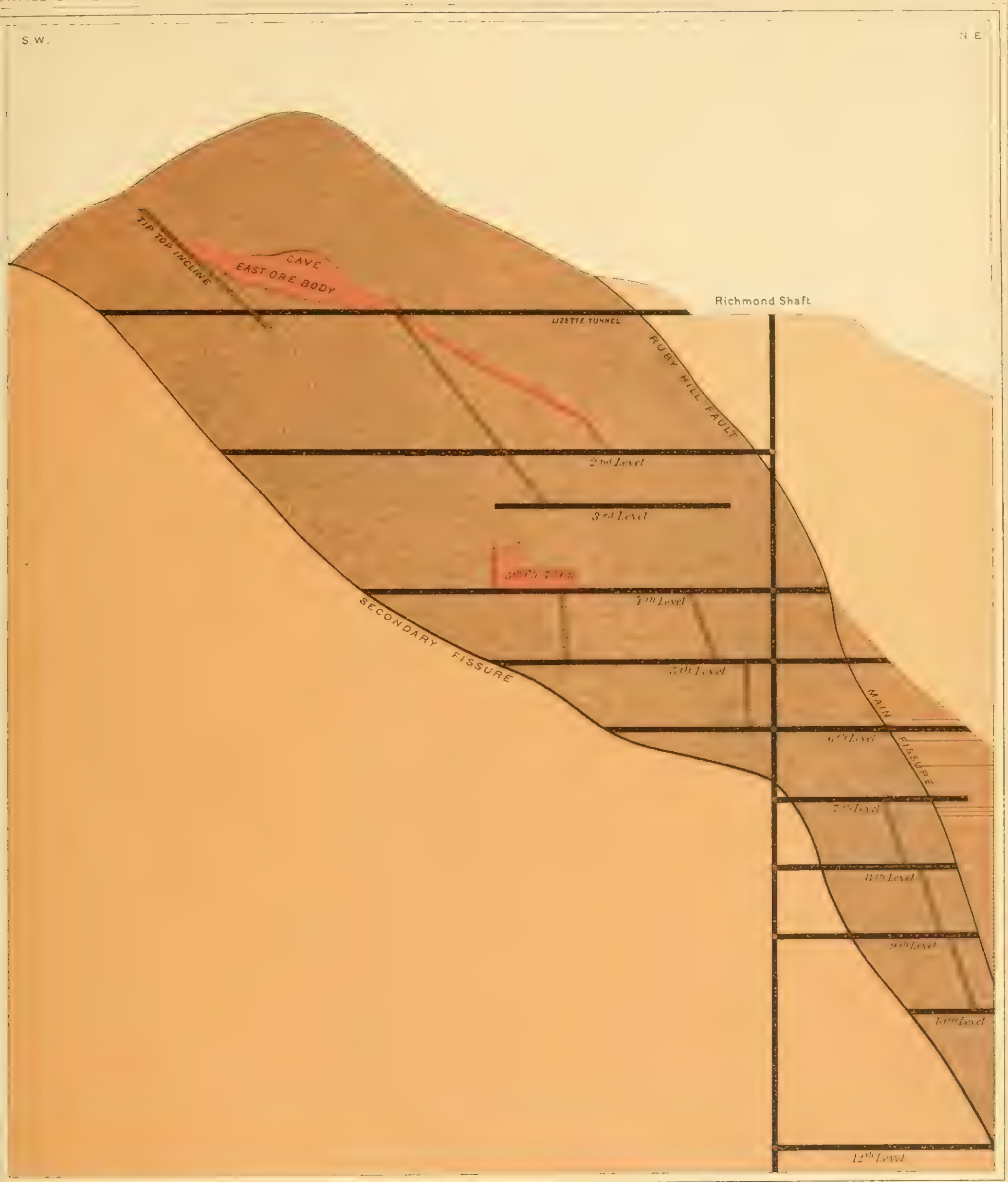
VERTICAL CROSS SECTION No. 8. RICHMOND MINE, THROUGH O. P.

Prospect Mt. Limestone.

Prospect Mt. Quartzite | Crushed Limestone | Stratified Limestone | Secret Cñ Shale | Ore | Fissures | Workings projected on the Section

FEET

METRES



Julius Bien & Co. Lith
J S Curtis, Geologist

VERTICAL CROSS SECTION Nº 9. RICHMOND MINE, THROUGH Q.R.

Prospect Mt Limestone

Prospect Mt Quartzite
Crushed Limestone
Stratified Limestone
Secret Cñ Shale
Ore
Fissures

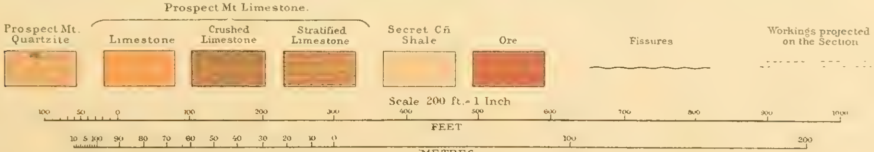
Scale 200 ft = 1 Inch

FEET

METRES

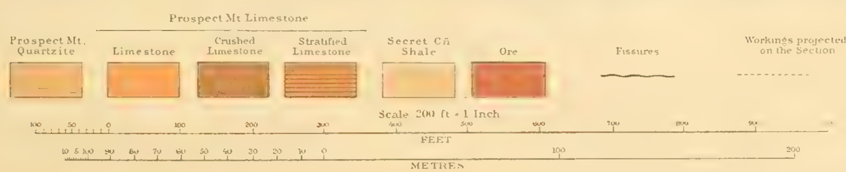
Julius Bien & Co. Lith.

VERTICAL CROSS SECTION No. 10. RICHMOND MINE. THROUGH S.T.



Julius Bien & Co. Lith.

VERTICAL CROSS-SECTION Nº 11 RICHMOND MINE THROUGH WV



into the Albion, where it is smaller and less distinct and probably disappears altogether.

The Ruby Hill fault and the quartzite.—Wherever the main fissure comes in contact with the quartzite the dip of the face of the latter corresponds with the dip of the fissure. The reason for this coincidence of dip is obvious. The face of the quartzite when in contact with the fissure is no longer the original contact of quartzite and limestone, but is the fault face of the southwestern uplifted country. The manner of this upheaval is explained in Fig. 2, Plate IV. The change of dip of the face of the quartzite when it comes in contact with the fissure can be noticed on the vertical cross sections (Plates V. to XII.). Up to the present time no signs of the fissure entering the quartzite have been observed, and it is not to be expected that it will do so until a much greater depth is obtained. Nevertheless, as all the shale and limestone beds and the quartzite pitch off flatter as the valley is approached, it is but reasonable to suppose that the fissure will eventually enter the quartzite unless the dip of the fissure also should decrease very materially. From the fact that an important fault has taken place on the fissure, it is not likely that depth will effect its dip in any marked degree. Neither is it probable that it will disappear at any depth to which explorations can be carried, as the fault which produced it is so widely extended.

Mr. Hague says that the thickness of the Prospect Mountain limestone can be taken at 3,050 feet. As close a calculation as it has been possible to make of the thickness of the bed of limestone between the lower or intercalated bed of shale and the Secret Cañon shale gives this bed a thickness of about 1,300 feet. Allowing 100 feet for the thickness of the lower shale, there remain 1,650 feet of Prospect Mountain limestone. This calculation is based upon the measurements that have been made near the Eureka main incline and the Locan shaft, and presupposes that the dip of the strata is 40°. If there were no other factors to be regarded, the distance at which the Ruby Hill fault could be expected to enter the quartzite would be about 2,200 feet below the twelfth level of the Eureka, or 3,230 below the top of the Lawton shaft. It is almost certain, however, that this distance will be very much decreased, owing to the fact that this lower bed of limestone has been very much crushed and pressed together by the

quartzite moving upward along the Ruby Hill fault. It is very likely that this distance will be considerably less, though there is not much probability that the fault will enter the limestone within 1,500 feet below the Eureka twelfth level. These calculations are made for the portion of country from which the ideal section, Plate IV., has been made.

Secondary fissure.—At the time of the disturbance which produced the main fault another and secondary fissure was formed along the contact of the quartzite and limestone, and the quartzite was raised higher than the limestone, giving rise to the formation of a limestone wedge between the quartzite on the one hand and the main fissure on the other. The dip of the quartzite contact does not greatly exceed 40°, while the dip of the main fissure is about 70°. The two surfaces of motion therefore approach each other and must eventually meet. In some mines this has already been shown to be the case, and the line of junction is exposed at various depths in the lower workings of those southeast of the compromise line. To the northwest of this line the lowest workings have not reached the junction.

The crushed condition of the limestone wedge is due to the upward movement of the southwestern country against the hanging wall of the main fissure. This upward movement also accounts in some measure for the disturbed nature of the contact between the quartzite and limestone, though there is no doubt but that there were many irregularities in this contact before the faulting took place. This is shown by the contact between shale and limestone, which is also very irregular, but it could not have been produced by the fault, as it lies in an undisturbed region. The undulations and protuberances in both quartzite and limestone were probably in the main produced by the primary folding which formed the hill.

Up to the present time all the ore of any importance taken from Ruby Hill has been extracted from the country southwest of the Ruby Hill fault, between it and the quartzite. The limestone northeast of the fissure, or the "front limestone," as it has been called, although it has been considerably prospected, has yielded no remuneration. An examination of the vertical cross-sections of the Ruby Hill mines (Plates V. to XII.) will explain the relative positions of the two fissures and of the limestone and ore between them, and the elevation (Plate III.) exhibits the line of their junction. In


American Shaft
Jackson Shaft
Phoenix Shaft
Lawton Shaft
K K Shaft
Old Jackson Shaft
RUBY HILL FAULT
MAIN FISSURE
JACKSON
PHOENIX
EUREKA
HORIZONTAL SECTION
American Shaft
Jackson Shaft
Phoenix Shaft
Lawton Shaft
KK Shaft
Old Jackson Shaft
MAIN FISSURE
RUBY HILL FAUL
JACKSON
PHOENIX
EUREKA
HORIZONTAL SECTION
Prospect Mt Quartzite
Secret Cñ Shale
Limestone
Magnetite Impregnation
Crushed Limestone
Ore
Shale
Rhyolite
Stratified Limestone
Fissures
Prospect Mt Limestone
Scale 400 ft = 1 Inch
Lawton Shaft
KK Shaft
RUBY HILL FAULT
EUREKA
HORIZONTAL SECTION N

HILL MINES, THROUGH A B

HILL MINES, THROUGH C D

HILL MINES, THROUGH E F.

J S Curtis, Geologist

HORIZONTAL SECTION Nº 1. RUBY HILL MINES, THROUGH A B

HORIZONTAL SECTION Nº 2. RUBY HILL MINES, THROUGH C D

HORIZONTAL SECTION Nº 3. RUBY HILL MINES, THROUGH E F

some places the cross-sections show that the dip has again become slightly flatter in the deepest workings, but this is probably not a permanent change.

Two belts of shale exist.—It has already been mentioned that two belts of shale, only one of which appears at the surface, exist on Ruby Hill. If the geological map of the district (Plate I.) is examined, it will be noticed that the shale and limestone contact on the surface lies at a considerable distance northeast from the Jackson, Phœnix, K. K., and Eureka mines. Taking into account the general dip of the Secret Cañon shale on the surface and that of the shale where it is encountered below, it is at once apparent that the two must be distinct masses. On the third and fourth levels of the Jackson mine, in the cross-cut to the old shaft, a body of shale upwards of 100 feet thick is encountered, which lies on the east side of the main fissure and dips away from it.

Lower belt of shale in the American and Jackson.—This lower shale has been faulted by the fissure, and the western portion has been raised up and can be seen in the American shaft cross-cut, described on page 28. Here it occupies the position where it was to be expected, namely, on the west side of the Ruby Hill fault. This is the only known place where this underground or lower belt of shale is to be found on the surface, the faulted portion having been removed by erosion at all other points aboveground.

In the cross-cut on the third level of the Jackson it is about 50 feet east of the main fissure and on the fourth it is in contact with it. It is upwards of 100 feet thick on the third level and widens out somewhat as depth is attained, so that in the cross-cut on the fourth it is 145 feet wide. The dip of the contact of the shale with the limestone on the third and the rhyolite on the fourth is 70° toward the northeast. The dip of the stratification, at its contact with the limestone or rhyolite, is very nearly the same as that of the contact itself, but in proceeding toward the old shaft the planes of bedding of the shale become flatter, though they again dip off more sharply as a fault plane is approached, which separates the shale from the black stratified limestone in which the old shaft was sunk. The stratified limestone northeast of this fault plane exhibits the same phenomena as regards dip as did the shale at its contact with the limestone or the rhyolite. The dip of this fault plane is about 70° northeasterly, and it

has a northwesterly and southeasterly course. No rhyolite accompanies it, but between it and the succeeding stratified limestone there is the ordinary clay produced by attrition. The phenomena just described conclusively prove the uplifting of this country in benches.

The quartzite was most raised, sliding along its contact with the Prospect Mountain limestone; this limestone also being uplifted along the fissure while the shale was raised along the fault between it and the stratified limestone. During the upward motion of these different benches each rising portion drew along with it more or less that which next succeeded. This is visible in the present arrangement of the strata. In ascending it will be observed that the main fissure, which faults or cuts off the shale, is no longer in contact with this rock on the third level of the Jackson, Fig. 2, Plate V. This is probably owing to the irregular form of the shale mass.

The lower shale in the Phœnix.—The next place where the shale is encountered is on the sixth level of the Phœnix. It is laid bare by a northeastern cross-cut 50 feet long 300 feet northwest of the northeastern cross-cut from the main incline. At the point where it is to be seen it is but 50 feet from the main fissure, but as the drift does not pass through it it is not possible to determine whether the same fault exists that is to be found on the northeastern side of the shale in the Jackson. It is altogether probable that it does, however, and that this is the same body of shale that is exposed in that mine, as its position is that which would be occupied by the Jackson shale did it follow the course and dip which has been exposed in the cross-cuts to the old Jackson shaft. Moreover it occurs on a line between the next shale encountered in the Eureka and that found in the Jackson. The Phœnix shale also does not appear on the surface.

Lower shale in the K. K.—There is probably shale to be seen in the lower workings of the K. K., but as everything in that mine has been flooded below the sixth level for several years, it was not possible to examine the ground, and information in regard to it was not reliable, as the clay in the main fissure has often been described as shale. Still as shale is encountered in the lower levels of the Eureka and Phœnix mines, it is likely that it is to be found in those of the K. K.


HORIZONTAL SECTION No. 4, THROUGH G.H.
Lawton Shaft
Albion Shaft
Richmond Shaft
HORIZONTAL SECTION No. 5, THROUGH I.J.
Lawton Shaft
Main Incline
Richmond Shaft
HORIZONTAL SECTION No. 6, THROUGH K.L.
Lawton Shaft
Albion Shaft
Richmond Shaft
Main Incline
Logan Shaft
Supposed Quartzite and Shale contact
Dividing Line between Richmond and Eureka Mines
Dividing Line between Richmond and Albion
EUREKA CON.
RICHMOND
ALBION
Julius Bien & Co. Lith
J S Curtis, Geologist
Prospect Mt Limestone
Prospect Mt. Quartzite
Limestone
Crushed Limestone
Stratified Limestone
Shale
Secret Cn Shale
Fissures
Cross Fissures
Scale 400 ft = 1 Inch.
FEET.
METRES

Lower shale in the Eureka.—This underground shale is exposed in the cross-cut from the twelfth level of the Eureka mine to the Locan shaft. Vertical cross-section No 7, Plate VIII., shows the position of this shale. At this point it is very narrow, not exceeding 20 feet, and is more or less mixed with stratified limestone. In this region it probably extends up as high as the little tenth, and it forms the hanging wall of the main fissure, which takes up the space between it and the quartzite. During the process of upheaval which formed the main fissure and the secondary fissure at the contact of the quartzite and limestone, there was considerable motion along the face of the quartzite, and the shale which lay northeast of the fissure was dragged upward, so that where it forms the hanging wall the dip of its stratification is nearly parallel with that of the fissure. This can be noticed in the cross-cut. The natural dip of the shale, however, is less than 40°, so that as depth is attained it will gradually pitch off flatter and the limestone will again make its appearance in the form of a wedge between the fissure and the shale. This occurrence is already indicated on the thirteenth and fourteenth levels, where the limestone appears to be growing wider. This limestone, having been subjected to a pressure similar to that exerted in the upper wedge between the hanging wall of the main fissure and the quartzite, will be found to be in a like crushed and broken state. At a point on the tenth level just over the main incline, 140 feet above the twelfth, the shale is found in contact with the main fissure, which is here some distance from the quartzite. In going southeast from this point the shale gives out, but in going northwest it is found in contact with the fissure. Further along toward the compromise line the cross-cut passes through it for 120 feet before reaching the limestone. Above this point the shale reaches as high as the little tenth, always forming the hanging wall of the fissure, but was not found where the fissure has been cut above it on the ninth. Below the twelfth level it was not possible to inspect it, as the thirteenth and fourteenth levels have been under water for several years, but from information obtained it must occupy about the position laid down on the map.

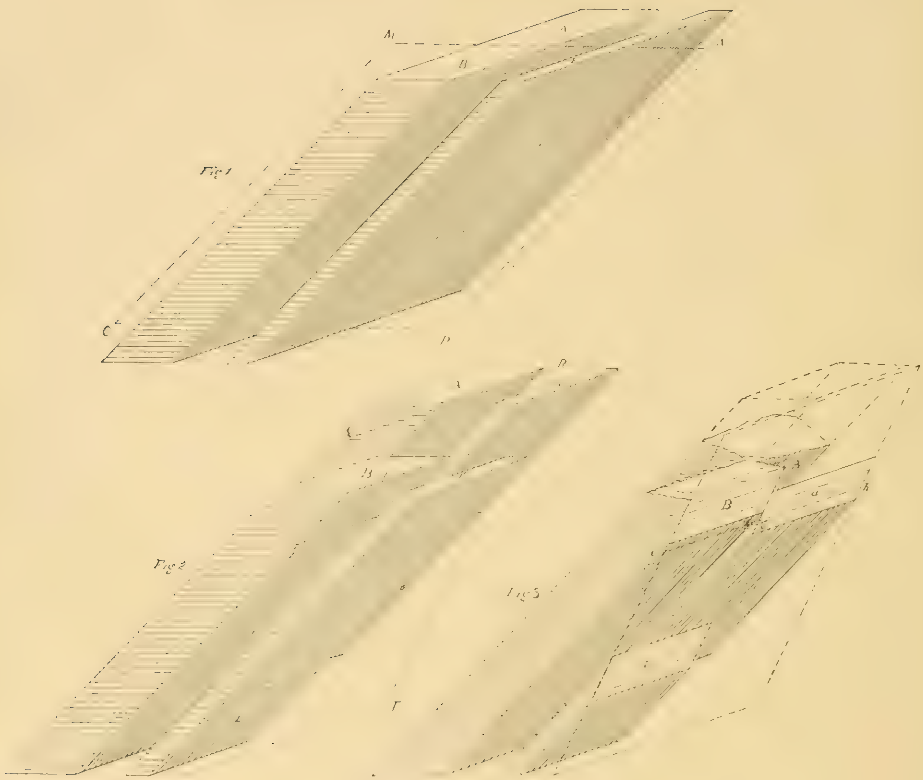
This shale may or may not be the same as that which is found in the Phœnix and Jackson, but the fact before mentioned, that it lies in a line

with those two belts and also that it is accompanied by a fissure on its hanging-wall side similar to the one which occurs in a similar position with it in the Jackson mine, would tend to prove that these three bodies of shale were parts of a continuous belt. They are moreover identical in their physical character.

Connection of the two belts of shale.—If the shale is traced from the point where it is found over the main incline on the tenth level of the Eureka past the compromise line into the Richmond seventh, and from the seventh up to the sixth, and so on up to the fourth, and thence through the shaft to the surface, the continuity of shale from the lowest workings of the Eureka up to the spot where it comes to the surface back of the Richmond hoisting works is established. But, on the other hand, if it is followed upward from the place where it is exposed in the cross-cut to the Locan shaft on the twelfth level of the Eureka along the line of its contact with the main fissure, it is lost sight of above the little tenth level of that mine. If it followed the fissure, it would be found on the surface about 800 feet southwest of the Locan shaft, and in the Bell shaft tunnel. But the shale on the surface lies over 300 feet northeast of that shaft. There is no other shale on the surface between the Locan and Lawton shafts, and none is found in the former shaft until a depth of 1,020 feet is attained. The shale on the surface, however, northeast of this shaft can be followed around to the southwest of the Richmond hoisting works, so that the two masses of shale, the upper and lower, must be connected somewhere below, the Locan shaft being sunk in the limestone between them. (See Plate I.).

Causes which produced the junction of the two shale belts.—Through the faulting incident to the upheaval the lower belt of shale has been brought into contact with the upper or surface shale somewhere near the compromise line. At exactly what point this junction takes place, it is a difficult matter to determine, except on the tenth level of the Eureka and the seventh and eighth of the Richmond, owing to the insufficiency of the explorations and the broken character of the ground; but it is evident that there is a junction as will be seen if the surface map is compared with the underground sections.

There is a sharp bend in the shale contact on the surface along the compromise line. From observations made below on the sixth, seventh,



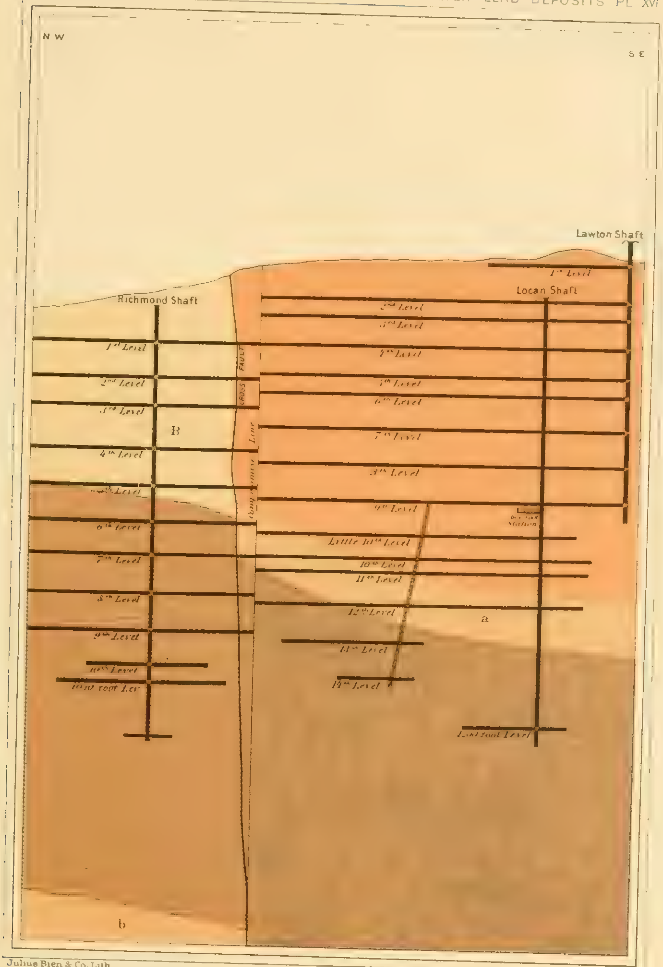
IDEAL FAULTING OF THE TWO SHALE BELTS.

and eighth levels of the Richmond, it is almost certain that this bend in the shale is not due to twisting and distortion, but was caused by a vertical fault which followed very nearly the course of the compromise line. When the country was raised up, the portion of it lying northwest of the compromise line fault was not raised to the same height as the portion of country lying on the southeast side of it. In other words, the block of ground just described subsided either absolutely or relatively. It is almost certain that in this manner the northwest end of the underground or lower body of shale was brought in contact with the surface or upper belt of shale along this compromise line fault. The position of the two bodies of shale southeast of the compromise line favors this belief. Similar cross-faults noticed in the quartzite in the Richmond mine also tend to prove the fact of a frequent cross-faulting of the formations in this part of the hill. This being the case, the lower belt of shale must underlie the stratified limestone in the Richmond mine, and it will be encountered at greater depth. At this lower level the ground must have very much the same appearance as the country on the northeast side of the main fissure in the cross-cut to the Locan shaft. The fissure, however, at the point where it cuts this lower belt of shale might or might not be in contact with the quartzite. A calculation made on the basis of the displacement of the shale on the surface would bring the lower belt of shale in contact with the fissure at a point about 1,700 feet below the top of the Richmond shaft, or about 500 feet below the present lowest workings. Another proof that the lower belt of shale has been brought into contact with the surface shale near the compromise line is furnished by the fact that the surface or upper bed of shale is always underlain by distinctly stratified limestone whereas the lower shale is not. This stratified limestone is not to be seen southeast of the compromise line or fault, where the lower shale makes its appearance. It will be noticed that this cross-fault does not in any way affect the course of the Ruby Hill fault; it was, therefore, formed at the same time or prior to it.

Illustration of the manner of faulting.— Figures 1, 2, and 3, Plate XV., represent the manner in which the two belts of shale were dislocated by the cross-fault and the main fault. A B, Fig. 1, represents the upper or larger belt of shale, and *a b* the lower, there being limestone between and on either side

of them, which, however, for sake of clearness, is omitted in the diagrams. The point of view is in the Richmond ground looking towards the Eureka, and the two bodies of shale dip easterly at an angle of 40°. The plane M N O P, Fig. 1, represents the direction of the cross-fault, which was the first one to occur. This fault takes place nearly on the compromise line, and has a nearly vertical dip. When the faulting occurred the blocks B and *b*, representing portions of the two shale belts, slipped down until they occupied the positions relative to the blocks A and *a* shown in Fig. 2. The plane Q R S T shows the direction of the main fault, and after it occurred the pieces *a′ b′* and B′ were raised above the present surface of the ground, and have been removed by erosion. The piece *a′* corresponds to the shale which was cut off from below the ninth level of the Eureka; the piece *b′* is the corresponding portion of the lower belt of shale, supposed to exist below the present workings of the Richmond, and B′ is the part of the larger mass of shale, which was removed by the main fault. The face *a*, Fig. 3, represents the shale as it now exists in the Eureka, and the face B represents the shale in the Richmond. The irregular lines on the tops of blocks A and B represent the surfaces of erosion as nearly as possible as they exist at present. If the line *e f g h* is taken as representing the Richmond seventh and the Eureka tenth levels, it will be seen that conditions exist in these ideal beds of shale similar to those which actually occur in the two mines. In the Richmond the contact between shale and limestone is continuous to the surface, and it can also be traced in to the Eureka ground along the tenth level of that mine, but cannot there be followed to the surface.

Plate XVI. represents a projection of the different formations that are found on the hanging wall of the main fissure upon a vertical plane parallel to its course. The point of view is from the mineral zone. The various beds of shale are lettered to correspond with those in Fig. 3, Plate XV. As the strata of shale and limestone were not only very much crumpled and disturbed before the faulting took place, but during that dislocation as well, the structure of this country is very complicated, and it is a matter of great difficulty to trace the movements that have taken place.



Julius Bien & Co. Lith

J.S. Curtis, Geologist

VERTICAL PROJECTION – HANGING WALL OF THE MAIN FISSURE IN THE RICHMOND AND EUREKA MINES

Prospect Mt Limestone.

Limestone. Crushed Limestone Stratified Limestone. Shale Secret Cñ Shale

Scale 400 ft - 1 Inch.

FEET.

METRES

Shale in the Albion.—A large part of the work which has been done in the lower levels northwest of the A C[a] line has been performed by the Richmond company.

On this end of the hill the shale does not present any remarkable features. Its contact with the limestone is irregular, as usual, but its position underground conforms very nearly with that which it occupies on the surface, always allowing for the dip of the formations. There are occasionally masses of it intruded in the limestone. South of the Albion shaft it is in close proximity to the quartzite, touching it in places. The quartzite referred to is a narrow belt of quartzite, which will be described hereafter. The shale is shown in the various horizontal sections, and it retains its general relations to the limestone down to the deepest point west of the A C line, namely, at the end of the ninth level of the Richmond.

Front limestone.—The time and manner of formation of the Ruby Hill fault, and its subsequent filling either with rhyolite or clay, are matters of very great importance as regards the history of the mineralization of the limestone between the quartzite and the fault-fissure and the prospects of finding ore either at a greater depth or by prosecuting developments in the so-called front limestone. This body of rock lies northeast of the main fissure, and although it has in many places the appearance of the ore-bearing ground has hitherto been found unproductive, all the ore having been obtained from the limestone wedge between the main fissure and the quartzite. It is true that the prospecting done in the front limestone has not been sufficient to prove that it contains no ore bodies, but it has been sufficient to discourage search in that direction. It shows at any rate no such outcrops as were apparent in the Champion, Buckeye, and Tip-Top claims (the original locations of the Eureka Consolidated and Richmond companies), situated in the southeastern slope of Ruby Hill, just above the quartzite and limestone contact. If the theory, which will be discussed hereafter, is correct, namely, that the ore was brought up in solutions from below through the main fissure, the barrenness of the front limestone is easily accounted for

[a] The A C line is parallel to the compromise line, and is the dividing line between the Richmond and Albion ground, which was established by the courts in the suits between the two companies. Prior to the fixing of this line the Richmond company had explored a large portion of the ground which is now held by the Albion.

by the presence of the lower belt of shale. The shale in general is unfavorable to the passage of solutions of any kind, as well as to the deposition of ore, and in this particular instance (see Plate VIII.) it acted as a barrier to confine the metalliferous solutions to the wedge of crushed limestone above it, between the main and secondary fissures.

Front limestone in the Eureka.—The explorations in the front limestone consist of a few cross-cuts from the different levels of the K. K. and Eureka mines. The principal of these cross-cuts is the one connecting the twelfth level of the Eureka with the Locan shaft. This cross-cut is 508 feet long and is driven from its junction with the twelfth level, near the station of the main incline, in a northeasterly direction, through the upper belt of Prospect Mountain limestone lying between the upper and lower belts of shale. The rock through which it passes does not differ in any material respect from the limestone which is found above between the quartzite and main fissure; but it is harder and more compact, and does not show evidences of having been crushed and disturbed to the same extent as the latter, except in the immediate neighborhood of the fissure. It is dark colored, and shows some slight signs of stratification.

Front limestone in the K. K.—The cross-cut on the sixth level of the K. K. (see horizontal section No. 2, Plate XIII.) lays bare another portion of the front limestone. This drift is over 300 feet long, and although the limestone is different in color and texture from that in the cross-cut just described, there is no greater difference than can be observed in varieties of limestone in the mass between the quartzite and fissure. Samples for assay were taken every 30 feet in this drift, and the results obtained will be discussed in the chapter on assays. No signs of stratification were observed in this limestone, and it was of a grayish-white color. It is harder and more compact the farther it is removed from the contact with the fissure, and it is highly crystalline in texture. It is considerably broken near this contact, and portions of it are crushed and mixed with the clay. The limestone between the fissure and this quartzite is crushed to a powder in many places, and forms a narrow belt scarcely a foot wide, which is often stained with iron. In another cross-cut, some 30 feet long, farther to the southeast, the limestone is of a blackish color, and breaks in sharp angular pieces. Similar

material, however, can be found in many places in the mineral belt, and this dark rock exhibits no characteristic features that would distinguish it as coming from the front limestone.

Characteristics of the front limestone.—It has not been possible to find any characteristic features in either of these two limestones which would distinguish them from each other; and although the limestone southwest of the fissure certainly belongs to the lower belt of limestone and that northeast of it to the upper, yet there is nothing in the appearance of either that would indicate that they belonged to different masses unless it is that the front limestone is less disturbed and that its stratification is more frequently perceptible.

The quartzite southeast of the compromise line.—The quartzite in the four mines southeast of the Richmond shaft appears to be substantially a solid mass many hundred feet in thickness. Its contact with the limestone is very irregular, and the rock near the surface is often displaced to a greater or less extent by faults, but it is comparatively easy to explain these irregularities and to account for the phenomena exhibited. Not so, however, with the quartzite in the Richmond and Albion ground northwest of the working shaft of the former mine.

The quartzite in the Richmond and Albion.—The explanation of the occurrence of this quartzite and of the manner in which it was brought into its present position in this part of the hill is a matter of great difficulty, partly owing to the absence of sufficient explorations in the neighborhood of the Richmond shaft and partly on account of the complex character of the movements which have taken place. The quartzite (see Plate III.) on entering the Richmond ground from the Eureka bends toward the west, as has already been stated, and forms a promontory which pitches to the north. This rock is first encountered in the Richmond shaft at a point about 30 feet above the seventh level and the shaft continues in quartzite down to the deepest point reached, namely, a perpendicular distance from the surface of 1,230 feet, which would give the quartzite a vertical thickness of at least 580 feet. A cross-cut on the twelfth level, driven a little east of north, passes through 360 feet of this rock before reaching the limestone. A cross-cut on the 1,050-foot level driven a little west of north strikes the limestone

160 feet from the shaft. It will be seen that both of these cross-cuts are run through the above-mentioned promontory, and that they give some idea of its shape at the depth at which they were run. These cross-cuts and other workings in the Richmond ground near the compromise line prove that the quartzite in which the shaft is sunk is the main body of quartzite which underlies the limestone of Ruby Hill. (See Plate XIV.)

The narrow quartzite.—At variable distances, according to the depth attained, northwest of the Richmond shaft, the secondary fissure, as the contact fissure between quartzite and limestone has been called, leaves the main body of quartzite and passes off into the limestone. It can be seen on all the levels of the Richmond and Albion mines where the workings have been pushed sufficiently to the south and west, but it is particularly well developed on the second and fourth levels of the former, where its course has been followed by drifts until it disappears in the northwest portion of the Albion ground. The most remarkable feature connected with this fissure is the fact that it is accompanied by quartzite. In the upper levels this quartzite is a very thin band, seldom exceeding 10 feet, and often much less, but in the lower levels it is much wider, reaching a breadth of 80 feet on the Richmond ninth level. Its junction with the main body of the quartzite is not clearly shown on any of the levels, but it is considerably northwest of the shaft in the upper levels, and gradually approaches the shaft, as depth is reached, until on the ninth level it is at about the point shown on the horizontal section No. 6, Plate XIV. The fissure is plainest on the upper side of this narrow belt of quartzite, but a parting is nevertheless distinguishable in many places on the under side. There are several cross-faults and undulations in this quartzite, which were probably produced by the primal upheaval. As the problem of the occurrence of the quartzite in this portion of Ruby Hill is as complicated as that of the shale near the compromise line, a detailed examination of its appearance is necessary to a full comprehension of the phenomena attending the formation of the mineral zone.

Description of the quartzite in detail.—In the Richmond the quartzite is first encountered on the second level, but it has not been as thoroughly explored on that level as it has been on the fourth, 200 feet below it. It is not certain at

exactly what point on this latter level the quartzite begins to thin out, but an alteration in its width is first noticeable about 800 feet westerly from the shaft. (See Plate XIII.). Here the quartzite is but a few feet thick, and a short distance farther to the west it is but a few inches, being scarcely more than a seam filled with quartzite, limestone, and clay. This character it retains in the continuation of this level, varying in thickness from a few inches up to 20 feet or more until the extreme northwest workings in the Albion ground are reached. Near the point where this thinning out of the quartzite is noticed there are unmistakable signs of a fault. This fault is of no great lateral extent, and forms one of a series of similar faults which are found in this narrow strip of quartzite at various points on the different levels. These faults have a general northerly course, and dip sometimes easterly and sometimes westerly. What has been the extent of the faulting in a vertical direction cannot be determined with any certainty, but in some cases it has been considerable. At the point mentioned above, there are two slips; but it is the one which has a westerly dip of 85° that seems to displace the quartzite. One hundred feet beyond this point a drift has been run into the "back lime," as the limestone is called which lies on the southwestern side of this narrow strip of quartzite.

In proceeding along the fourth level from the shaft, the main body of quartzite is left at some unknown point, the explorations that have been made in the back lime not having been sufficient to discover it, and the narrow band that is followed is but a splinter from the main mass. On the Richmond fifth level the quartzite is to be found at two points. The first is about 200 feet south of the shaft, and the second is at the end of the first southwest cross-cut. In both places it appears to be the main solid body. Still it is possible that at the last point it may be only 50 feet thick, for it is found no wider than that on the sixth level 100 feet below and some little farther west. The explorations on the sixth level (Plate XIII.) lay bare the contact of the quartzite and limestone for a long distance. The end of the long southwest cross-cut, which is called the fissure drift, reveals the same fault in the quartzite that is exposed on the fourth. In the southeasterly branch of this southwesterly fissure drift the quartzite is found to be 50 feet thick. It is faulted and brought down to a seam by the fissure which

followed the southwestern branch of this drift, but in all probability it widens out again in the manner shown on the map, as it is found at the southeast on the first level of the Albion 30 feet above the Richmond sixth. It there follows a course almost identical with that exposed above it on the fourth. It seems to have the same bends and twists exhibited on that level, and it is likely that its position at any intermediate point between the two levels could be calculated within a few feet. Both in the Albion first and in the Richmond fourth, 170 feet above it, the quartzite also comes in contact with shale bodies, and the manner of occurrence in the two cases is very similar. The quartzite on the Albion first is very narrow, and although it lies along a well-defined fissure it is not an easy matter to obtain characteristic specimens, as it is much mixed with limestone and clay.

On the seventh level of the Richmond there is a fault 190 feet from the shaft, but it lies over 200 feet to the southwest of the point at which its position above would indicate its reappearance. The quartzite and its accompanying fissure is found at the southeast end of the Albion second or intermediate level. At this point it has been cross-cut ten feet and the back limestone has not been encountered. In following along this level, the fissure, which is here nearly perpendicular, leaves the quartzite. It is true that this fissure contains more or less clay and quartzite for a considerable distance, but the limestone on the southwest side of it does not seem to have the usual characteristics of the back limestone. In passing along the eighth level a fault is again noticeable, at a point where there is a sharp bend in the drift 390 feet west of the shaft. The point is nearly directly below the fault on the sixth.

As the seventh level does not extend far enough south to expose this fault, were it in the position on that level indicated by its occurrence on the sixth and eighth, it is impossible to tell whether the fault which is exposed on the seventh, 190 feet from the shaft, is the same as the one on the sixth and eighth. It possibly is another fault, but those exposed on the sixth and eighth must be identical. Shortly after leaving this point nothing more is to be seen of this quartzite on the eighth level until it is laid bare in the south cross-cut west of this fault. It is here about 30 feet wide, and is somewhat different in character from the ordinary quartzite. It is grayish

in color, rather slaty or laminated in texture, and sandy to the touch. A close examination, however, shows that it is quartzite. This cross-cut is run some distance into the back lime, which has its usual habitus. The quartzite is again laid bare on the third level of the Albion, which corresponds with the Richmond eighth, in two westerly cross-cuts from the Albion shaft. The quartzite has been faulted by a fissure near the winze which descends from the Albion second, and is not visible along the southeasterly drift.

On the ninth level of the Richmond (Plate XIV.), which is run almost entirely in back limestone, the quartzite, except near the shaft, is of the same character as that which appears in the south cross-cut on the eighth. Near the station, another fault is discovered. Again the question arises, Can this fault be in any way connected with the others above it? It is most likely a separate fault which here shows itself for the first time. Southeast of the shaft, toward the compromise line, the quartzite retains its normal character and apparently its normal thickness.

On the ninth level the narrow belt of quartzite must join the main mass somewhere between the north cross-cut from the water drift and the shaft. What the position of this dismembered mass may be on the 1,050-foot and lower levels future developments alone will show. In descending, this belt of quartzite widens until on the ninth level it reaches a width of over 80 feet in places. On both its hanging and foot wall sides, but especially on its hanging, it exhibits signs of considerable motion, and it is more or less mixed up with limestone at the planes of contact, and occasionally contains fragments of the latter rock even at a considerable distance from the limestone. Its lamination seems to be due rather to the effect of movement under immense pressure than to the manner of deposition. Where the quartzite is found unbroken and of the normal character it shows no such indications of stratification.

Dip and strike of the thin quartzite.—The dip of the contacts of this belt of quartzite is much greater in many places than that of the main mass, although its irregularities are such that it is impossible to make an exact determination. The average dip in the levels above the Richmond ninth is about 45°, but in the lower levels it would correspond more nearly with that of the main fissure. The course of this quartzite is very tortuous, as a reference to the

various horizontal sections will show; but it is remarkable in this respect, the irregularities nearly correspond on all the levels.

Relations of the quartzite and secondary fissure.—The motion of this quartzite upward along the plane of its contact with the limestone has already been mentioned. It is a difficult matter to tell what has been the extent of the upward motion, but that it has been very considerable is shown by the comminution of the quartzite and limestone at their contact, and the numerous striation marks where either of these rocks have remained in a solid condition. When the main fissure was made and the faulting took place which raised that portion of country lying southwest of the fissure, the quartzite was moved up, not only along the fissure, but also along the plane of its contact with the limestone, and the limestone wedge between the quartzite and the fissure slid back against the limestone hanging wall. The upward motion of the quartzite crushed and otherwise dismembered the limestone lying between it and the solid northeastern wall. When the fissure between the quartzite and limestone reached a point southwest of the present Richmond hoisting works, it shot off into the limestone instead of following around the contact plane of these two rocks, which turns towards the south. The continuation of this quartzite fissure is the fissure which is found in the Richmond and Albion mines accompanying the narrow band of quartzite, and which has been described in detail. The Ruby Hill fault fissure lies much farther to the northeast, near the shale, and has also been described in detail. The positions of these two fissures and their relations to each other can be observed in the different maps and diagrams. They are designated by heavy black lines.

The manner in which the narrow band of quartzite found its way into its present position seems to admit of but one solution, namely, that its occurrence is due to a succession of faulting movements which followed the line of the accompanying fissure, and that it originally formed part of the main body of quartzite which must here underlie the limestone. It is altogether improbable that it constituted a distinct bed of quartzite laid down upon the back limestone. In this case some indications of its existence would have been noticed in other parts of Ruby Hill. It is not possible

either that it is quartz, and was deposited after the formation of the fissure, as under the microscope it exhibits the structure of quartzite.

Relation of the two fissures to the country rock.—The two fissures, the secondary and main fissures, do not exhibit a width which is in any way proportional to the amount of movement which has taken place along their planes. The main fissure in the Eureka, and other southeastern mines, is very strong, often having a width of 12 feet or more, but in the Richmond and Albion it is scarcely more than a seam, and would naturally not be considered of much importance if the great difference in the country rock on each side of it was not taken into account. The secondary fissure, although it is always accompanied by more or less clay, does not always exhibit absolute proof of its nature, and in some places might be mistaken for the ordinary contact of two dissimilar rocks, but when considered as a whole and in conjunction with the narrow strip of quartzite in the Richmond mine the fact that it is a distinct rent in the earth's crust can hardly be disputed.

Back limestone.—This term is used in reference to the limestone which is found on the foot-wall side of the narrow band of quartzite, which in the Richmond and Albion ground accompanies the secondary fissure. In the cross-cut run into the limestone at the point on the fourth level already mentioned (page 45), the quartzite appears in the roof of the main drift, and is scarcely more than a foot wide. Except that it is mixed more than usual with clay and limestone, it differs in no way from the ordinary quartzite. It has the same pinkish color and friable nature. The back limestone is pulverized almost to a powder at the contact, but becomes more compact as the drift penetrates farther from the fissure. This limestone differs in a great many respects from the limestone which is encountered between the quartzite and shale. It is blackish, breaks with an angular fracture, has a somewhat glassy appearance, and its planes of fracture are lined with quartz or calcite. It is a highly metamorphosed and somewhat silicified limestone, and contains some bituminous matter. As yet no ore of any kind has ever been found in it. Its peculiarities are very characteristic, and it is easily recognizable wherever found. Specimens taken at a depth of 900 feet are not distinguishable from those that have been taken at four.

Relation of the Ruby Hill fault to the Jackson fault.—If the surface-map, Plate I., is examined an extensive fault will be noticed just east of the Jackson hoisting works. This fault extends a considerable distance to the north and south, and has been called by Mr. Hague the Jackson fault. The main fissure of Ruby Hill, the one containing rhyolite, joins the Jackson fault somewhere south of the American shaft, but at exactly what point has not yet been determined, the surface of the ground being covered by débris, while the underground developments are inconsiderable. It has been stated that the limestone in which the American shaft is sunk is the Pogonip limestone. It is therefore possible that the main fissure of Ruby Hill is identical with the Jackson fault at this point, though the fault laid down by Mr. Hague runs nearly due north from the American shaft. That there is another fault parallel to the main Ruby Hill fissure is clearly shown on the cross-cuts to the old Jackson shaft, and it is probable that this other fissure is no other than the one which Mr. Hague has called the "Jackson fault." There seems to be very little doubt that the eruptions of rhyolite which occur in this neighborhood, of which Purple Mountain is a prominent example, are intimately connected with all these faults.

CHAPTER V.

ORES OF PROSPECT MOUNTAIN AND RUBY HILL.

Classification of the Prospect Mountain and Ruby Hill ores.—The ores of Ruby Hill are to be classed under the head of argentiferous-auriferous lead ores. They are of two classes, oxidized and unoxidized, though up to the present time almost all the ores produced by the mines of Ruby Hill have been of the former character, sulphurets being only found in a very few places in a region two or three hundred feet above the water level and in some localities below it. As might naturally be expected, the line which divides the oxidized from the unoxidized ores is not sharply defined, and the transition is a gradual one.

Influence of the water-level on oxidation.—In some places where ore is found at a considerable distance below the water-level, it is in an altered condition, which would seem to point to the fact that the present water-level is somewhat higher than it has been at some previous time. This is probably the case, as it is not possible that oxidation could have taken place at any considerable depth below the surface of the water. The workings of the mines of Ruby Hill have at present reached a depth of over 1,200 feet, the deepest point being the bottom of the Richmond shaft. The greatest depth attained in the old workings of the Eureka is 200 feet higher than the bottom of this shaft. From the lower workings of the Eureka up 200 feet the ground has been flooded for several years. The water rises 150 feet in the Richmond shaft, but remains at that point. From this it will be seen that there is a difference in water-level of 250 feet between the two mines. The surplus water from the twelfth level of the Eureka flows down a winze to the Richmond ninth level, 70 feet below, and finally reaches a permanent level in another winze 180 feet deeper. In the Richmond mine no ore has been found below the ninth level, 900 feet from the surface, so that it cannot be determined with certainty what its mineralogical character may be below the water-level.

It will be noticed from a reference to the actual water-level line marked on the elevation (Plate III.) that it is very irregular, showing that there is not everywhere a free circulation of water between the extreme workings on the mineral zone, as well as that the water-level at the northwest end is very much below that at the southeast. The irregularity in the character of the ore in the neighborhood of the present water-level is no doubt due to the rise and fall of the water at different periods, and to the nature of the ground, which in some places is more accessible to the action of the air.

Local differences in the Ruby Hill ores.—Although there are some slight local differences in the ores produced by the mines of Ruby Hill, they are so inconsiderable that it is not necessary to describe them by localities, and although their variety is very great, yet the different oxidized ores do not seem to be confined to any one level or any particular chute of ore, but occur indiscriminately at all depths. Sulphurets, particularly galena, are found to some extent intermingled with the oxidized ores, but those represent mere remnants which have escaped oxidation and are usually insignificant in quantity. Masses of sulphurets occur only below or near the water-line.

Minerals occurring in Ruby Hill.—Before describing the different varieties of ore found in the mines of Ruby Hill, it may be well to mention the minerals of which they are composed. It is very possible that other minerals than those which are given in the following list occur, but as their presence has not been detected in the careful examinations which have been made of the ores, it is not likely that they exist in any great quantity, or that they are very numerous.

The galena is usually of a medium grain, and more or less mixed with sulphate of lead. It occurs in the form of nodules, which are changed at the surface into sulphate and carbonate of lead, and in irregular masses distributed throughout the ore. It is often of a dull black color, owing to the admixture of sulphate, and contains small quantities of arsenic and antimony, and in some cases molybdenum, which is probably in the state of sulphide. It usually carries from \$100 to \$150 per ton in silver and from \$1 to \$10 in gold. It is richer in silver and poorer in gold than the average ores. Pseudomorphs of galena after other minerals, although they may exist, have not been noticed. This fact renders it improbable that any sulphide of lead has been deposited since the period of oxidation.

Anglesite (sulphate of lead) is an important mineral in the composition of the Eureka ores. It forms a large portion of the "yellow carbonate" of the miner, and is present to some extent in all the lead-bearing ores of the hill. It is the product of the decomposition of the galena, and occurs in three forms: as colorless crystals in geodes in the galena and other ores in a manner that shows that it was deposited from a solution of the sulphate; in compact masses of a dull black color, usually containing undecomposed sulphide and a kernel of galena; and in finely divided particles disseminated throughout the ore. In the latter case it is not distinguishable by the eye, and its presence can only be detected by the usual tests for sulphuric acid and lead.

Cerussite (carbonate of lead) almost always occurs crystallized, sometimes in acicular crystals mixed with other minerals throughout the ore; sometimes in geodes and surrounding nodules of galena and anglesite, and in massive aggregations of small crystals of a dark color. In this latter instance it is called "sulphuret ore" by the miners, and probably contains an admixture of mimetite, as arsenic acid can often be detected by means of the blow-pipe. The dark color is due to the presence of manganese. It is evidently the ultimate product resulting from the decomposition of the galena after that mineral had been changed into sulphate. It seems also to exist disseminated in a finely divided state throughout the so-called "red carbonate," a mixture of different lead minerals and hydrated oxide of iron, for this ore gives a reaction for carbonic acid while it contains scarcely any lime.

Mimetite[a] (chloro-arsenate of lead) is found in colorless crystals

[a]Analysis of colorless mimetite from the Richmond mine, Eureka, Nevada, by F. A. Massie, of the University of Virginia:

The specimen consisted of slender, almost acicular, hexagonal prisms, aggregated into a friable mass, with a few small crystals of wulfenite scattered throughout it. The individual crystals were colorless and transparent, with adamantine luster and white streak, the general aspect of the mass very much like that of cerussite. Hardness = about 3; sp. gr. = 6.92; very easily fusible. Analysis gave:

As_2O_5	23.41
Pb_2O_5	trace
PbO	68.21
$PbCl_2$	8.69
	100.31

In accordance with the well-known formula:

$$PbCl_2.\ 3\ Pb_3As_2O_8.$$

and in yellow masses more or less mixed with sulphate. The occurrence of crystals is rare, but the "yellow carbonate" often contains considerable quantities of this mineral. As the galena which has been found in the mines of Ruby Hill rarely contains much arsenic, it is not likely that mimetite was formed through the oxidation of galena alone, but that it resulted from the simultaneous decomposition of that mineral and arsenopyrite. This is made probable by the fact that the "yellow carbonate," a widely distributed ore, although it is sometimes composed of sulphate of lead and hydrated oxide of iron alone, is usually a mixture of sulphate of lead, chloro-arsenate of lead, and hydrated oxide of iron. If the "yellow carbonate" resulted from the decomposition of arsenical galena alone it would not contain the hydrated oxide of iron except as an admixture. That the iron is not always an ingredient resulting from a subsequent mixture of the products of oxidation is shown by fragments here and there in the mass which retain the original structure of the minerals which composed them.

This mimetite has been found in the form of stalactites, stalagmites, and in columns in vuggs in some of the ore bodies. It occurs as minute hexagonal crystals surrounding a core of some brown mineral, which is probably limonite. The vugg in which the specimen belonging to the collection was found occurred in the upper part of an ore body, which was distinctly stratified, indicating that the material composing it had been re-arranged since it was oxidized. The minerals in the interior of the vugg had evidently been crystallized from solutions since the rearrangement of the ore. The manner of formation of these stalactites, etc., seems to be plain. The arsenopyrite, pyrite, and galena, which formed the original ore, were oxidized, sulphate of iron being first formed. This sulphate of iron trickled down, forming numerous columns, upon which the later product of decomposition, mimetite, was afterwards deposited. In time the sulphate of iron lost its sulphuric acid and became limonite, which remained as a core.

Wulfenite (molybdate of lead) is of frequent occurrence in the ores of Ruby Hill. It is found as aggregates of fine tabular crystals coating nodules of galena changed into sulphate and carbonate, and frequently mixed with crystals of the latter as well as in minute crystals disseminated

throughout the ore. Some of the galena contains considerable molybdenum, but whether the quantity contained in it will account for the presence of the considerable amount of wulfenite in some of the ore is a matter of doubt. From the manner in which some of it is found surrounding nodules of galena carrying molybdenum, and from its occurrence mixed with the other products of decomposition of that mineral, it is evident that a portion of it at least was formed by the decomposition of the molybdenum-bearing galena. Thus far the existence of molybdenite (sulphide of molybdenum) has not been detected in the oxidized or unoxidized ore. It exists, however, in the underlying quartzite. Several specimens of this mineral were found in sinking the Richmond shaft from the 900 to the 1,200-foot level, also in the cross-cut from the 1,200-foot station through the quartzite to the limestone. As it is usually found in the quartzite, it is in a very finely divided state, and were it not for the few exceptional specimens that have been found, its presence would have been overlooked. It is probable that its occurrence in the quartzite is due to secondary causes, and that, like the pyrite, it was not an original constituent of that rock. It is not improbable that it will be found in considerable quantity in the unoxidized ore below the water level.

Pyrite and arsenopyrite both occur in the unoxidized ores, and the former is found in the quartzite and in some of the other rocks of Ruby Hill. Arsenopyrite is not as plentiful in the unoxidized ores as the amount of arsenic in combination with lead in the oxidized ores would lead one to expect, if the theory that arsenopyrite was the original source of the arsenic is correct; but the bodies of sulphurets hitherto discovered have been so few and small that they cannot be taken as representing quantitatively the minerals which originally composed the oxidized ore bodies. Marcasite has been observed in the shale.

Limonite (hydrated sesquioxide of iron) is the principal component of the Ruby Hill ores. It stains the ore from a light brown to a deep reddish-brown according to the quantity present and the extent of its hydration, and together with mimetite forms the coloring matter of the "yellow carbonate." It is sometimes found compact, but is usually unevenly distributed throughout the mass of the ore. Pseudomorphs of this

mineral after pyrite have occasionally been observed. Hematite (sesquioxide of iron) is also present in the ore, but it is not as often met with as the hydrate.

Blende (sulphide of zinc) is found to some extent in the upper portions of the mines, and is of frequent occurrence in the lower workings in connection with pyrite and galena. It is usually a dull black cryptocrystalline substance, but is sometimes crystalline. In the latter form it is found in the "black" chamber between the eighth and ninth levels of the Eureka mines.

Calamine (silicate of zinc) is often met with in fine characteristic crystals in connection with earthy limonite. It usually occurs at the junction of ore bodies with the limestone, and in many instances is pseudomorphous after that rock.

Smithsonite (carbonate of zinc) is no doubt present in the ore and is the product of the decomposition of blende, but no characteristic specimens have been noticed. Zincite (oxide of zinc) is probably present, but its detection is difficult on account of the admixture of iron in all the ores.

Calcite (carbonate of lime) is everywhere found in the Eureka mines. It occurs transparent, but is usually of an opaque milky color, cementing together the crushed mass of the rock and in clumps of crystals in vuggs and other cavities. Calcite is of rare occurrence in the ore itself. The calcite, as well as the limestone, carries more or less carbonate of magnesia, but none has as yet been found which contains sufficient of that substance to entitle it to the name dolomite.

Aragonite (orthorhombic carbonate of lime) is of frequent occurrence. It is particularly plentiful in the caves and smaller cavities of the limestone, where it often covers the entire roof and walls. In many places it is constantly forming from the water which is oozing from the limestone. It occurs in the form of radiating groups of acicular crystals and as fibrous crusts and nodules covering the débris on the floors, as well as on the sides and roofs of the caves.

Measurement of the growth of aragonite crystals.—Some observations were made in a large cave between the ninth and tenth levels of the Eureka mine in regard to the growth of these crystals, which were measured as follows: A co-

ordinate scale pasted on a board was hung directly behind the group of crystals, the growth of which was to be measured, and a transit instrument was placed at a convenient spot at from 10 to 15 feet in front of the scale. It was found convenient to use a transit, as the construction of this instrument permitted the removal of the telescope without the derangement of the tripod, and as the moisture collected so fast on the lenses within the telescope that it was impossible to observe the crystals if it was left underground over night. When the telescope was replaced it could be put exactly in its former position, thus preventing any inaccuracies which might arise from the removal of the point of observation from the original line of sight. The temperature in this case remained at nearly $54\frac{1}{4}°$ F. (30.1 C.), the variation not being $1\frac{1}{4}°$ F. during the whole time (some six weeks) over which the observations extended. The moisture in the atmosphere was very near the dew-point, as was shown by a very slight decrease in the temperature upon moistening the bulb of the thermometer. The water was dripping from many points in the roof of the cave, and the sides were wet with it.

During the first period of observation the maximum growth of any of the crystals observed was five-sixteenths of an inch in three weeks. This particular crystal began its growth in a large drop of water, which gradually diminished in size until at the end of three weeks it had totally disappeared. During the first part of this time the crystal formed most rapidly, and seemed to shoot out of the drop of water. Its increase was then perceptible from day to day. The growth of this crystal, as well as others in the group, was evidently dependent upon the size of the drop of water surrounding it, for although the whole of the group of crystals was wet increase was only perceptible in those crystals surrounded by a drop of water. No definite growth within a given time could be fixed upon as normal.

The maximum growth in another aggregation of crystals observed for a like period of three weeks was found to be three-eighths of an inch, and the general conditions and results were similar to those noticed in the first instance. It will be noticed that the evaporation of the drops of water was comparatively rapid, notwithstanding the fact that the temperature was close to the dew-point. This is explained by the character of the ventilation of

the cave, which at its lowest point was connected with the main incline and at its highest by means of a winze with the ninth level above. Although the atmosphere remained near the dew-point, it was constantly renewed. The observations were conducted very near the center of the cave.

Roth[a] says that spathic and fibrous calcium carbonate (calcite or aragonite, or both together) are common in the form of stalactites and stalagmites in the cavities and fissures of limestone, and in the tunnels, shafts, and drifts of the mines. Dana[b] mentions that it is forming in an old mine in Monte Vasa, Italy, at a temperature below the boiling-point of water. The conditions which govern the formation of aragonite and calcite, respectively, are not understood. In Ruby Hill, however, aragonite is forming under ordinary pressure at a low temperature.

Siderite (carbonate of iron and lime) has been frequently noticed.

Quartz is found in crystals in cavities and mixed through the ore at rare intervals It is not an important mineral in the ore, except that it is necessary to its reduction by smelting.

A silicate of iron has been noticed, but it is not of common occurrence.

Clays which are more or less mixtures of silicate of alumina, carbonate of lime, oxide of iron, and other substances, are to be found at the contacts of the different formations, and at numerous places in the ore-chambers. These clays are sometimes merely the products of attrition of the two walls of a fissure, and again have been produced by the decomposition of igneous rocks or an infiltration from above. Steatite and talc are occasionally met with, but are unimportant

Rarer minerals.—Molybdenite has been detected in the quartzite from the bottom of the Richmond shaft, and both carbonates of copper (malachite and azurite) have been met with in small quantities. As phosphorus has been found in some of the ores it is highly probable that pyromorphite is present. It is also likely that leadhillite (sulphate and carbonate of lead) as a distinct mineral may occur here (if anywhere), as admixtures of sulphate and carbonate of lead are very common. Oxide of lead as a mineral has not been found in the ores in the course of the present examination,

---

[a] Roth: Algemeine Geologie. I., p. 534. Berlin, 1879.
[b] Dana: System of Mineralogy, p. 696. New York, 1874.

though it may exist. It is not likely, however, that if it formed at any time it could remain long in quantity uncombined with carbonic acid in the presence of waters carrying so much of that compound. Wad has been observed in the Phœnix mine and in some other localities; also other forms of manganese in different places, and nickel is said to have been found, though no specimens have been obtained.

Miners' classification of ore.—The ores of the district are not accurately classified by the miners, but receive names indicative of their most striking characteristics and the popular idea of the corresponding composition. It may be well to describe some of the more important varieties. Most of the ore has a reddish or yellowish color, due to the presence of oxide of iron, chloro-arsenate, or molybdate of lead. The shades of color vary according to the predominance of one or the other of these minerals and the quantity of earthy material mixed with them. One of the principal kinds of ore is composed of a hydrated oxide of iron mixed with some sulphate and carbonate of lead and containing intermingled grains and lumps of undecomposed galena. This ore is often called "red carbonate." It usually carries about equal values of gold and silver, from $25 to $50 of each per ton, though sometimes the gold is considerably in excess. Another variety is the "yellow carbonate." This term is applied in general by the miners to any ore of a yellow color which contains lead. It belongs particularly, however, to a very characteristic ore, which is a mixture of the hydrated oxide of iron with the sulphate and chloro-arsenate of lead in varying proportions. The ratio of the silver to the gold in this ore is not at all uniform; sometimes one metal, sometimes the other, being in excess. The value of both metals does not usually exceed $100 per ton. Another variety of "yellow carbonate" is that which owes its color to the molybdate of lead mixed through it. As the molybdate of lead usually carries but little silver and less gold, this ore is not very rich unless it contains other minerals bearing the precious metals. The so-called "sulphuret ore" of the miners is an almost pure crystallized carbonate of lead. It is grayish in color, and consists of aggregated crystals of cerussite. It is sometimes quite rich in silver, assaying as high as $125, but like all the lead ores proper is poor in gold. There are several varieties of red ore, consisting principally of the hydrated oxide

of iron, with a little lead and silver, which are tolerably rich in gold. There is usually nothing in their appearance to indicate their value, and it is only by constant assaying that it is possible to determine what they are worth.

Quartz ores, especially those carrying quartz in visible crystals, are uncommon, except in the Eureka Tunnel and some parts of Prospect Mountain, but when found they are usually rich in gold and poor in silver and lead. There is a porous crystalline quartz ore found in some places in the Richmond mine, from which assays of over $300 per ton (.04977 per cent.) in gold, with but a few dollars in silver, have been obtained. The sulphuret ores usually consist of a compact mass, composed of pyrite, arsenopyrite, galena, and blende, and vary very considerably in the amounts of silver and gold that they contain. The miners do not as yet distinguish different varieties by name.

Analysis of Richmond ore.—The following analysis of ore from the Richmond mine for the year 1878 will serve as an example of the ores from all the mines of Ruby Hill, which greatly resemble each other both as regards quality and the minerals which compose them. The sample analyzed was an average of all the Richmond ore worked at the furnaces of that company during the previous year, and the analysis was made by Fred. Claudet, of London.[a]

	Per cent.		Per cent.
Lead oxide	35.65	Lead	33.12
Bismuth	———		
Copper oxide	.15	Copper	.12
Iron protoxide[b]	34.39	Iron	24.07
Zinc oxide	2.37	Zinc	1.89
Manganese oxide	.13		
Arsenic acid	6.34	Arsenic	4.13
Antimony	.25	Antimony	.25
Sulphuric acid	4.18	Sulphur	1.67
Chlorine	———		
Silica	2.95		
Alumina	.64		
Lime	1.14		

[a] Copied, by permission, from the records of the company.

[b] In this analysis the iron is represented in the form of protoxide, whereas it occurs as sesquioxide. That it was intended to give it in the form of sesquioxide is shown by the percentage of iron (24.07) given would correspond with 34.39 of sesquioxide.

Magnesia	.41
Water and carbonic acid	10.90
Silver and gold	.10
	100.52

27.55 Troy ounces[a] silver per ton of 2,000 pounds.
1.59 Troy ounces[b] gold per ton of 2,000 pounds.

Although this analysis does not show all the substances that are present in the ores of the Richmond mine, yet it represents the most important and principal ones. One of the remarkable features of this ore is its freedom from earthy material, the total amount of silica, alumina, lime, and magnesia that it contains being but 5.14 per cent. That it should contain but a small quantity of silica is but natural, as there are no highly silicious rocks immediately connected with it, but that it should carry such a small percentage of lime and magnesia, occurring as it does almost wholly in a limestone formation, is a fact that it is somewhat difficult to account for. Whatever the source of the ore may have been, it is evident that it was deposited almost entirely free from earthy material. The hydrated oxide of iron may be regarded as the gangue of this ore.

Discussion of the analysis.—Upon examining this analysis it will be noticed that the lead has been estimated in the form of oxide. The lead, however, is present in the form of galena, carbonate, sulphate, molybdate, arsenate, and chloride, the chloride being combined with the arsenate in the mineral mimetite, which is of frequent occurrence in the ore. The mineral pyromorphite may be present in the ore, but it has not been detected, although there is a trace of phosphoric acid present. Lead is also present in other forms, but as they represent in the aggregate but a small proportion of that metal they may be regarded as merely accessory It is difficult to estimate the proportion of the different lead minerals contained in this ore, but it is probable that galena (sulphide), cerussite (carbonate), and anglesite (sulphate) are present in about equal quantities, and the next most important combinations are mimetite (arsenate and chloride) and wulfenite (molybdate).

When copper has been detected in the ore it has been in the form of carbonate. Zinc has been estimated entirely in the state of oxide, but it

[a] $35.61. [b] $32.87.

occurs in the form of blende (sulphide), calamine[a] (silicate), and probably as smithsonite (carbonate). It is most common in the form of calamine. Manganese occurs mostly as wad. Arsenic is almost entirely combined with lead as arsenic acid, and the same is most likely the case with the small percentage of antimony which the ore contains.

In the above analysis it will be seen that the sulphur has been estimated almost entirely as sulphuric acid, although it is partly combined with lead in the form of galena. Most of the sulphuric acid is combined with lead, though to some extent it is no doubt combined with calcium. Silica is present in the form of quartz principally and combined with iron and aluminium. The calcium and magnesium are present, combined for the most part with carbonic acid.

The silver is found in the form of chloride and sulphide, and the gold exists in all probability in a finely divided metallic state. In this analysis no account has been taken of the chlorine, and for some unaccountable reason molybdic acid has been omitted. It must have been present in the ore analyzed, as wulfenite is a common mineral in the Ruby Hill ores. The footing of the different elements in this analysis amounts to 100.52, but it would be considerably less if a portion of the sulphuric acid had been estimated as sulphur, which would leave room for several substances which are unquestionably present.

In a qualitative analysis of the Ruby Hill ores, Dr. Melville, of the United States Geological Survey, detected the following elements:

Gold.	Aluminium.	Chlorine.
Silver.	Calcium.	Phosphorus.
Lead.	Magnesium.	Silicium.
Copper.	Arsenic.	Carbon.
Zinc.	Antimony.	Molybdenum.
Iron.	Sulphur.	Manganese.

Relative value of the ores of Prospect Mountain and Ruby Hill.—The ores of Prospect Mountain are very similar to those of Ruby Hill, though perhaps there is a greater

[a] In this report the word calamine will be used to designate the silicate of zinc, and smithsonite for carbonate of zinc, this being the nomenclature adopted by Dana. These terms have been used by various writers in a promiscuous manner, some using smithsonite to designate the silicate, and calamine the carbonate. Brogniart used calamine for silicate and smithsonite for carbonate. Brooks and Miller in 1852 reversed these names. Quenstedt called the carbonate calamine and the silicate willemite.

variety of them. As a rule they contain more silicious material, and as a class are probably richer than those of the hill. The difference in value is in part owing to the fact that the deposits are smaller, and although it cannot be said in reference to this district that small deposits in general are richer than large ones, yet it is true that the ores brought to market from Prospect Mountain are more valuable than those from Ruby Hill, inasmuch as a body of ore of considerable size can be made to pay even when the ore is of a low grade, whereas a small one containing the same grade of ore would not yield sufficient metal to defray the expense of mining. A large number of the mines of Prospect Mountain, however, actually contain higher-grade ores than those of Ruby Hill.

Varieties of Prospect Mountain ores.—The ores of the Ruby-Dunderburg mine closely resemble those of Ruby Hill. The ores of the Eureka Tunnel, on the other hand, which is at present the principal producing mine on Prospect Mountain, differ in several respects from those of Ruby Hill. They are more silicious, an ore occurring frequently which is composed in great part of quartz; a great deal of the arsenic acid in the yellow carbonate is replaced by antimonic acid; massive blocks of so-called "black metal," a mixture of sulphide and sulphate of lead carrying considerable silver (sometimes as high as $1,000 to the ton), are often met with; carbonate of copper and oxide of manganese are not uncommon, and quartz crystals are frequently found scattered through the ore.

The ores of the mines on the west slope of the mountain are noted for the relatively larger proportion of gold to silver that they contain. Among the richest of these are the ores of the Silver Connor and Williams mines. The ore from the former of these mines contains but little lead. The ore of the Banner mine is noted for the large amount of silica it contains. It can almost be called a quartz ore. The Dead Broke ore contains considerable argentiferous galena and "black metal."

CHAPTER VI.

THE ORE DEPOSITS.

Classification of the ore deposits.—The ore deposits of Eureka District, though they contain gold, can be classed under the head of silver-lead deposits in limestone The type of deposits to which those of Eureka belong is one often met with in the older limestones of the Great Basin, and although these particular deposits have been of more value, and are more widely known than any of the others, and exhibit some very interesting structural features, yet they cannot be said to form an isolated class. An extended comparison of these deposits either with similar ones in the Great Basin or with others of the same general character elsewhere, does not come within the scope of this report, but it may be well to present some points, both of resemblance and difference between them and the best known examples of similar types in other mining regions. Although the gold and silver in the Eureka ores are the metals which render their mining possible, yet the quantity of them present in these ores, measured by weight, is so small, in comparison with the lead, that a classification based upon these metals alone would be misleading. As in many of their features they resemble other lead deposits in limestone, it seems best to regard them simply as lead deposits, in which the gold and silver are merely accessory, though very important ingredients. All lead ores carry some silver, and with it some gold, though in many of them it is only possible to obtain traces of these metals.

Lead deposits in limestone of the Great Basin.—Throughout the Great Basin there are a large number of lead deposits, all of which exhibit many features of similarity. They occur in limestones and dolomitic limestones of Palæozoic age, and are mostly of very irregular form. Their ores consist principally

of argentiferous galena with antimonial and arsenical combinations and pyrite and the decomposition products derived from these minerals. Compounds of copper, zinc, and other metals occasionally accompany these ores. In by far the greater number of instances the oxidation has been carried to a great depth, sometimes reaching or exceeding 1,000 feet. The extent of this oxidation is in a great measure due to the absence of any large quantity of water until considerable depth is reached. The characteristic gangue of these ores is the hydrated oxide of iron with more or less calcite. Quartz is rarely found in any great quantity, except where the deposits occur in the form of contact lodes between limestone and porphyry, the quartz being probably derived from the decomposition of the porphyry. An example of such lodes is offered by the 2 G. mine in Tybo District, Nye County, Nevada. It is found to be more profitable to reduce all these ores by smelting than by any other process. Among the principal districts where such ores are found may be mentioned Eureka, White Pine, and Bristol, in Nevada; Cerro Gordo, in California, and Ophir, Big Cottonwood, and Little Cottonwood, in Utah—all of which occur in Palæozoic rocks, though in some cases, at all events, the deposition of ore is referable to a much more recent era.

Deposits of the Upper Mississippi.—The lead deposits of the Upper Mississippi[a] occur in dolomites of the Lower Silurian. The ore is found in caves, in openings between the strata, and in so-called gash veins. The stratification of the country rock is flat, and it shows scarcely any signs of dynamic disturbance or alteration through chemical causes even in the neighborhood of the ore. The lead is found almost always in the form of galena, accompanied by limonite and occasionally smithsonite (zinc carbonate) and blende, rarely by pyrite. Calcite and barite occur, but quartz and combinations of lead with arsenic are not met with. The galena contains but traces of silver and gold. There are no signs of fissure veins and the ore is not found at any great depth below the surface. From the occurrence of the galena in the forms of stalactites and stalagmites in the caves, and the absence of decomposition in the country rock near the deposits, it is evident that the openings were first formed and the ore was deposited in them from solu-

[a] J. D. Whitney. Metallic wealth of the United States.

tions or otherwise, and that substitution of minerals for country rock played no important part. With regard to the age of the country rock and the occurrence of limonite with the galena, these deposits resemble those of Eureka District, but in other respects, such as structure and manner of ore deposition, they differ widely.

Deposits of Missouri.—The lead deposits of Missouri and Arkansas also occur in the dolomites of the Lower Silurian. The ore is galena, with but traces of silver and gold. It is often accompanied by calamine (zinc silicate) and limonite. It is found in nests in clay, also in beds as fine impregnations in the calciferous limestone, as well as in flat masses between the strata. In the flat veins cerussite occurs. Galena is also found in impregnations in dolomite and in cavities and caves mixed with gravel, zinc ore, clay, and barite. Calamine and some blende, as well as barite, almost always accompany the galena. Quartz crystals are also found. The occurrence of these deposits is very similar to those of the Upper Mississippi, but very dissimilar to those of Eureka.

Deposits of Leadville.—The deposits of Leadville, Colorado, resemble those of Eureka in a great many respects, as can be seen upon reference to an "Abstract of a Report upon the Geology and Mining Industry of Leadville, Colorado, by S. F. Emmons."[a] Mr. Emmons states that the investigations made in Leadville have proved the following facts:

"As regards their origin—

"I. That they have been derived from aqueous solutions.

"II. That these solutions came from above.

"III. That they derive their metallic contents from the neighboring eruptive rocks.

"IV. That in their original form they were deposited not later than the Cretaceous period.

"As regards their mode of formation—

"I. That the metals were deposited from their solutions mainly as sulphides.

"II. That the process of deposition of the vein-material was a chemi-

---

[a] Second Annual Report of the Director of the U. S. Geological Survey, 1881.

cal interchange or an actual replacement of the rock-mass in which they were deposited.

"III. That the mineral solutions or ore-currents concentrated along natural water channels and followed by preference the bedding planes at a certain geological horizon; but that they also penetrated the mass of the adjoining rocks through cross-joints and cleavage planes.

"And with regard to distribution—

"I. That the main mass of argentiferous lead ores is found in calcareo-magnesian rocks.

"II. That the silicious rocks, porphyries, and crystalline rocks contain proportionately more gold and copper."

As regards origin, the Eureka and Leadville deposits do not differ, except that in Eureka District the metal-bearing solutions came from below, and their connection with eruptive rocks is not as plain in Eureka as in Leadville.

As regards their mode of formation, the deposits of the two regions differ only in respect to the manner in which the solutions of minerals were distributed. In Eureka, also, the lead is found only in the limestone, and the most silicious rocks carry the most gold.

The varieties of minerals found in the two districts are similar, but the galena in Eureka seems to have been more completely oxidized than that in Leadville.

Deposits of Cumberland and Derbyshire.—The lead deposits of Cumberland and Derbyshire in England are found in the Carboniferous limestone, between the strata of which there are masses of porphyry,[a] which in that country are called "toadstone." The ore is found in fissures which cut the strata. With these fissures pipes, caves, and other irregular openings containing ore are more or less closely connected. Flat bodies or beds are also found between the strata. The fissures are mostly occupied by true lodes, which, however, do not contain ore where they traverse the porphyry, and are not

---

According to v. Groddeck (Lagerstätten der Erze, p. 245) it is doubtful whether this porphyry is intrusive or whether the limestone overlying it was deposited after its eruption. Investigation made by Mr. Emmons of the deposits in Leadville, which occur in limestones of the Carboniferous, seem to prove that the porphyry, which in that region is also found between the strata, is intrusive. And although this fact does not absolutely warrant the belief that such is the case with the deposits in England, it heightens the probability of such a manner of occurrence.

productive in the overlying millstone grit and slate. With the exception that the fissures themselves are not often ore-bearing and that almost all signs of stratification have been obliterated in Eureka, there are strong points of resemblance between the Nevada deposits and those of Cumberland and Derbyshire. The galena in the English ores[a] never contains over $37.70 (0.1 per cent.) of silver to the ton of 2,000 pounds, and it is usually poorer. It is not often accompanied by blende or pyrite. Fluorite and barite, as well as calcite, are common; but quartz is seldom found.

Deposits of Westphalia.—The ore deposits of Eureka resemble those of Westphalia[b] in a few respects. The ore in the latter locality is found in irregular masses, which are all more or less connected with fissures or breaks associated with slates and limestone. It occurs only in the limestone and never in the slate, and it is evident that in both regions the nature of the country rock has had an immediate effect upon the deposition of the ore.

Deposits of Upper Silesia.—The deposits of Upper Silesia,[c] in which calaminn is the prevailing ore, although they have some points in common with those of Eureka, are, on account of difference in structure and variety of minerals, more widely removed from them than most of the lead deposits.

Deposits of Raibl.—The deposits of Raibl, in Carinthia, so fully described by Pošepný,[d] have considerable similarity to those of Eureka, and although they are principally interesting on account of the bearing they have upon the theory of substitution of ore for limestone, yet a general description of them may be found useful here, as showing some physical characteristics which they have in common with those of Eureka. According to this author the deposits are found in a thick belt of ore-bearing limestone (erzführender Kalkstein), which overlies a calcareous tufa and underlies slate on the southern slope of the Alps. The strata pitch gently to the south. The upper portion of this ore-bearing limestone is more or less magnesian, and contains here and there layers of dolomite slate. The ore deposits are found concentrated on the hanging-wall side of these

[a] Henwood on Metalliferous Deposits and Subterranean Temperatures, Part I., pp. 108 and 109.

[b] v. Cotta: Erzlagerstätten, II., p. 133.

[c] Pietch, Zeitschr. für Berg, Hütten u. Salinenwesen, B. 21, 1873, p. 292.

[d] F. Pošepný: Die Blei- und Galmei-Erzlagerstätten von Raibl in Kärnten. Jahrb. der k. k. geolog. Reichs-Anstalt, Wien, 1873, B. XXIII.

layers. They have sometimes the form of lodes, sometimes of beds, and are often very irregular. The galena deposits are found principally in the dolomite and the calamine[a] deposits in the limestone. This formation is cut up by numerous fault-fissures (Blätte) which have a northerly course. These correspond exactly with those found in the Eureka mines, and are scarcely more than seams in the rock. The ore deposits are found along them, sometimes on one side and sometimes on the other, the enriching of the ore-bearing limestone seeming to depend upon the presence of fissures and the dolomite slate. Occasionally the ore deposits take on the character of lodes along these fissures, and sometimes they are connected deposits of very irregular shape. The stratification of the ore-bearing limestone is indistinct and in the neighborhood of the fissures it is crushed and broken. The lead ores are poor in silver. Further reference to these deposits will be made when the theory of substitution is examined.

Age of the deposits in relation to the formation.—The deposits of Eureka, as well as all those which have been mentioned, are unquestionably of later formation than the limestone or dolomite which contained them, and though but few of them can be reckoned among the lodes in the narrower sense of the word, yet they are all so intimately connected with fissures, crevices, and seams that they unquestionably owe their existence to the presence of fissures.

The discovery of a prototype for the deposits of any particular district is hardly possible, as no two portions of the earth's crust present exactly the same geological features, and if any two such existed there is no probability that they would both be ore-bearing, or, if they were, that they should have been supplied with ore by precisely the same agencies. The occurrence of silver in paying quantities with lead ores is very common, particularly west of the Rocky Mountains, but the presence of gold also in paying quantities, which forms so marked a characteristic of the Eureka ores, is exceptional.

Classification according to form.—A classification of the ore deposits of Eureka District as regards their form is a matter of considerable difficulty. There

[a] Pošepný used the word calamine to include both calamine and smithsonite.

are some of them which can be termed fissure or contact veins, but in most cases they are very irregular in form, and are better described by the German word "Stock" than by any mining term used in English. The word "pipe" can be applied to many of them, but in its ordinary use a "pipe" implies a "rake," while the ramified structure of the Cumberland deposits is rarely well marked at Eureka. They are often lenticular. This term, however, cannot always be used to describe their form, as they have offshoots in all directions. Any classification, however, which is dependent on mere differences of form must be more or less imperfect.

Shape of the deposits.—The deposits sometimes spread out into immense chambers that measure more than fifty feet in each direction, and which are completely filled with ore, with the exception of an occasional cave or limestone pillar. From the sides of these chambers, which scarcely ever present smooth walls, there are branches, and auxiliary pipes lead up or down, or in a horizontal direction, to other bodies. The ore bodies do not seem to follow any particular direction, either as regards dip or strike, and at first sight they appear to be distributed throughout the ore-bearing formation without any regularity. This is not wholly the case, and although no well-defined law can be found governing their occurrence, this is connected with that of certain phenomena in the country rock, such as fissures, caves, and broken limestone.

Relation of the deposits to the limestone.—The distribution of the ore has been determined almost entirely by the physical character of the limestone in which it is found, and not by any chemical or mineralogical differences in the rock. In other words, whether the limestone was dolomitic or not, and whether it was nearly pure or somewhat argillaceous, it was always a rock which would fulfill the chemical conditions necessary to the deposition of ore. Even supposing that dolomitic limestone is generally better adapted to induce deposition—and this is something which has never been proved—the greater facilities offered by a crushed and broken limestone, no matter what its character, to the percolation of the metal-bearing solutions, would more than compensate for any chemical advantages which a particular kind of limestone offered. Although the typical fissure vein is found in limestone in many parts of the world, its occurrence in that rock in the Great Basin

is rare. The rarity of this type of regular deposits at Eureka can be accounted for in a great measure if the extremely crushed character of the country surrounding them is taken into account. When the upheaval of the mountain ranges began, the rock was cracked and fissured in many directions, the fissures no doubt extending to great depths and having considerable lateral extent; but as the uplifting and grinding process was prolonged, these fissures themselves were in a great measure obliterated and faulted, new ones of less magnitude taking their place. This operation seems to have been carried on until the mountain was no longer a solid mass penetrated by great cracks, but was composed of shattered zones of limestone separated here and there by bodies of unbroken rock. The ore-bearing solutions entered the rock through the channels of least resistance, the crushed limestone offering less resistance in many places than the main fissures themselves, and deposition followed in forms of a degree of irregularity corresponding to the complexity of the preceding dynamical effects.

Disposition of the ore in the chambers.—The ore in the upper part of larger chambers is mostly in a loose state, sometimes in layers, and is usually covered by beds of sand, gravel, and bowlders of variable thickness. It is difficult to believe that this mass owes its structure to any other cause than rearrangement by subterranean water currents, though it is not likely that the original position of the material was remote from that which it now occupies. There is of course every reason to suppose that waters either from the surface or from below have flowed through these rocks in notable quantities ever since they were intersected by fissures, but the floods which have left the traces just described in the upper portions of the chambers must be comparatively recent, since the stratified ore has been rearranged since its oxidation. In the lower part of the chambers, on the other hand, the ore is more compact and usually appears as if it occupied its original position.

Connection of ore bodies with the quartzite.—On Ruby Hill, in the mines lying southeast of the "compromise line," the ore is usually found in the limestone at or near its contact with the quartzite, except close to the surface, where it is generally at some distance from that formation. Although a complete connection has not been established between all these ore bodies and the quartzite, or between all the ore bodies themselves, yet their location and

the relation that they bear to the secondary or contact fissure between quartzite and limestone indicate that that fissure has often served as an ore channel. This is more apparent as the ore is followed downward to the level at which it takes up the whole of the space between the quartzite and the main northeast fissure. (See cross-cut to Locan shaft, Plate VIII.) It has been mentioned that most of the ore bodies in the Eureka lay along the quartzite and limestone contact; but there has been one notable exception, namely, the seventh and eighth level ore body. This, with its ramifications, reached to the northeast clay in places and extended from a short distance below the fifth down to nearly the ninth level. It was the largest single mass of ore ever found on the hill, and from it were extracted over two million dollars. There have been several large bodies of ore near the quartzite in the K. K. mine, but, with the exception of a mass near the surface in the Jackson ground, the ore bodies in the portion of the mineral zones lying southeast of the Eureka have not been very large.

Northwest of the "compromise line" the ore has been found on the quartzite in only one place, viz., above the fourth level of the Richmond mine near that line. A reference to the various horizontal sections (Plates XIII. and XIV.) will also show that the mineral zone or the wedge of limestone between the two fissures is small in this part of the hill. The surface ore bodies at the Champion, Buckeye, and Richmond claims of the Eureka and Richmond companies were of very considerable extent, but at the present time it is difficult to say how much ore was extracted from them, as the workings have caved in many places and are inaccessible. In fact, exact data in regard to the quantity of ore extracted from any of the ore bodies, except those of the Richmond, are wanting; but as they are not necessary to a geological discussion of the Ruby Hill deposits, they can be dispensed with.

Occurrences of the ore bodies in Prospect Mountain.—There is very little difference in the manner of occurrence of ore bodies in Prospect Mountain and Ruby Hill. On the mountain there are no workings in the neighborhood of the quartzite, and thus far the metalliferous zones have been separated by belts of undisturbed limestone and shale. The size of the ore bodies in the

mountain has been much less than those in the hill, and the caves have been smaller and less numerous.

Fissures and faults.—Both Prospect Mountain and Ruby Hill are traversed by numerous fissures or faults. The more important and persistent of these follow the course of the axial plane of the anticlinal fold, which, in the case of Prospect Mountain, has a north and south course, and in the case of Ruby Hill, a northwest by southeast course, and dip away from it. There are, however, a great number of cross-fissures. The former seem to have been faults accompanied by upward movements, while the latter show that there has been lateral as well as vertical pressure exerted during their formation. As a rule these fault-fissures are mere seams, although they may extend several hundred feet in every direction. Sometimes, however, they are of considerable width, and have been partially filled with bowlders broken from the walls and débris washed in from above. They occasionally contain ore and in several cases assume the appearance of fissure veins. Where fissures containing lead ore occur in limestone in Cumberland, Derbyshire, and in many parts of Europe, the country is very much less disturbed than it is in Eureka, and the mountain folds are much less sharp. Examples of fissure veins are not absolutely wanting at Eureka. There is one in the Banner mine which crosses the axis of fold of Prospect Mountain, and is remarkably regular for a lode in limestone. The east ore body of the Richmond mine begins in the Tip Top claim, one of the location claims of the Richmond Company, and extends down to the Potts chamber on the "compromise line." A fissure seems to exist through the entire area thus indicated, and though the ore does not always fill the fissure and though the fissure itself often shrinks to a mere seam, the whole occurrence can properly be regarded as a fissure vein. In the Ruby-Dunderburg there is an instructive deposit which in some portions fills a clean-cut fissure a foot or more in width, and in which at some points the ore penetrates the hanging wall in large irregular outgrowths from the vein, which have supplied most of the ore.

Caves in connection with ore bodies.—Caves are found in many places in the limestone and are of frequent occurrence in connection with ore bodies; in fact, no large ore bodies have been found which had no caves over them; but

caves are by no means always accompanied by ore bodies. They resemble all caves found in limestone, and have been produced, in part at any rate, by the solvent action of water carrying carbonic acid. These waters passed through fissures and cracks, enlarging them, and dissolved the limestone, especially where it was crushed and broken. The finely crushed limestone was dissolved first, and the large fragments and bowlders settled down and were finally either completely dissolved or remained in the bottom of the caves. This action was naturally most considerable at those points where the best opportunity was afforded for the free circulation of the water, and as the limestone was not uniformly shattered, and as the different varieties of rock did not offer equal resistance, the openings formed were of a very irregular character. The roof and sides of the caves are sometimes entirely bare and only show the characteristic surface which results from the action of a solvent. Deposition of calcium carbonate, however, as well as its solution, has taken place on a large scale and is still going on. The roof and sides of most of these caves are covered by aragonite crystals, and in some of them crystals of this mineral are still forming.

Connection of ore bodies and fissures.—In the neighborhood of seams the limestone is often crushed to a powder or is broken into fragments, which are occasionally cemented together by calcite, forming a breccia. This fissured and crushed country gave ingress to waters both from above and below. The surface waters, owing to the carbonic acid which they contained, had a solvent action upon the limestone, and those from below carried ores in solution, which were, at least in part, substituted for the limestone. The waters from both these sources removed limestone, which was again deposited when the solutions became supersaturated. The question whether the caves were partially formed before the deposition of the ore, during its deposition, or after it, will be discussed hereafter; but it may be stated here that a great portion of the ore in these ore bodies was directly substituted for the limestone. The irregularity of the course of the dissolving waters is everywhere perceptible in the ore bodies and caves. They have every possible form and vary greatly in size, sometimes being but small stringers and occasionally measuring upwards of a hundred feet in all di-

rections. They are sometimes round, and again tabular, and are found with and without ramifications. There are pear-shaped deposits and pipes round and flat, irregular and symmetrical. A common form is that of a bent sausage somewhat flattened, and both ends downward. In fact, the form of the deposit has been governed by the permeability of the rock. Although these deposits are of all shapes and sizes, taken as a whole they have a downward trend; that is to say, they extend farther in depth than they do laterally. Some are found lying nearly flat, like bed veins, but this manner of occurrence can usually be accounted for by the hardness and insolubility of the underlying rock. The ore bodies at first sight often seem to have no connection with any fissure or channel through which they could have been filled, but such a connection has been demonstrated in so great a number of cases that it may be presumed to have existed in all.

In by far the greater number of instances this fissure has led to the discovery of the ore body, or its existence has been shown in the workings subsequent to the discovery. In some it has been closed by pressure, in others it has not been revealed by the explorations of the miner, who naturally does not think it necessary to follow every small crevice or opening which he may encounter. This connection of ore bodies with fissures is a very important one, as it throws a great deal of light upon the nature of the deposits, and although the fissure may apparently be very insignificant and nothing more than a seam in the rock, the crushing and rending of the limestone in its neighborhood attendant upon its formation have given the metal-bearing solution an opportunity of penetrating the rock, and although the fissure itself may not have been the ore channel, the formation of the ore bodies has been dependent upon it.

Example of connections between ore bodies and fissures.—Numerous examples of an evident connection between ore bodies and fissures are to be found in this district. Besides the east and west ore bodies of the Richmond mine, which will be more fully described hereafter, the Ruby-Dunderburg and Williams mines, on Prospect Mountain, are among the best instances of this occurrence; but examples of fissures connected with ore bodies have been found in almost all of the mines of the district. No doubt many of the deposits in limestone which occur at numerous points in the Great Basin would

exhibit similar features as regards fissures and ore bodies if they were more carefully examined.

The main fissures which follow the axial plane of the fold show that there was a zone of crushed rock produced in the country parallel to them. The dissolving waters followed this zone and often penetrated to a considerable distance laterally. When there is more than one fissure in such a zone it is a matter of great difficulty to decide which one ought to be considered the true ore carrier or decisive factor in determining the present arrangement of the deposits. Several fissures may have been instrumental in determining the ore channels.

Relative ages of fissures and ore bodies.—Although most of the fissures with which ore bodies are connected were unquestionably formed before the deposition of the ore, yet there are some few which may possibly have been made since its deposition. It is a very difficult matter, where there are no signs of stratification in the country rock, to tell whether a fissure has faulted an ore body or not. When two ore bodies are found at some distance from one another and on opposite sides of a fissure, it by no means follows that they were originally portions of a mass which has been faulted by the fissure. The two ore bodies may always have been distinct. There cannot have been much faulting since the deposition of the ore, for fissures, the existence of which prior to the deposition of ore cannot be disputed, show very few signs of any displacement.

The partial falling in of caves and the mixing of bowlders of limestone and ore near open fissures does not prove that there was any considerable motion of the country. The roof of the big cave between the ninth and tenth levels of the Eureka is falling in from time to time, but this is probably due to the chemical action of water loosening blocks of limestone, and the mixing up of ore and limestone in the northwestern portion of the Richmond mine below the seventh level can be attributed to the mechanical action of the same agent.

Sediment.—In connection with fissures it may be well to describe the transported material or sediment which is often an accompaniment of fissures and ore bodies. It consists of loose bowlders of gravel more or less connected together, of large and small brecciated fragments of limestone,

or of loose sand. Its nature, the position it occupies and its structure show that it could only have been brought into its present place by the aid of water. It is to be looked upon, therefore, as simply a wash from higher points which has filled the cavities and interstices of the rock formed by dynamic and chemical causes. This wash frequently accompanies large ore bodies, and is usually found adjoining or overlying the ore, and although it is not an infallible indication of its presence, it is one which is not to be overlooked. The two-million-dollar ore chamber on the eighth level of the Eureka mine was discovered by following such a wash. This body extended up above the seventh level and down nearly to the ninth, and covered a great deal of ground with its ramifications and pipes. On the other hand, there is a very large mass of material of a similar origin, in the form of fine sand, on the fifth level of the Phœnix, which, although pretty well prospected, has not led to any discoveries. These washes are more frequent at or near the surface, but are found down almost to the water level.

Description of east ore body.—It has already been remarked that the quartzite and limestone contact in the Richmond ground bends to the west, and the fissure that accompanies it continues with the narrow band of quartzite on its normal northwest course. Parallel with this fissure there is a system of fissures which extend from near the surface at the Tip Top incline down to the tenth level of the Richmond mine. These were accompanied by ore chambers which form an almost continuous body down to a point a little below the seventh level of the Richmond. Below this point no ore has been found in the Richmond in this part of the mine, although there is a well-defined fissure extending to the tenth level. From the position which this fissure occupies, however, it is almost certain that it is the Ruby Hill fault, and it is very probable that the system of fissures mentioned above joins the main one somewhere below the seventh level. From this it will be seen that the Tip Top fissure, or the "east ore body," is an offshoot of the main fissure which is shown at the winze on the ninth level on the horizontal section, No. 6, Plate XIV. One of the most famous of this series of ore bodies is the Potts chamber, most of which in the Richmond mine lies between the fifth and sixth levels. It is also connected with the series

of ore bodies which are found at the contact of quartzite and limestone in the Eureka ground.

Description of west ore body.—The west ore body, as the second system of chambers in the Richmond mine is called, begins near the surface in the Eureka ground in the neighborhood of the "compromise line." These chambers are all connected with one another in some manner, and most of them are connected with a system of fissures. It pitches north, and as depth is obtained passes through the Richmond and enters the Albion ground. It lies under and northwest of the east ore body, and does not in any place connect with it or directly with the Potts chamber. Nevertheless, as the upper part of the west ore body lies on or near the quartzite in the Eureka mine, and as in this mine ore is traceable along the quartzite to the Potts chamber, the two ore bodies are indirectly connected. The positions of these ore chutes can be seen in the vertical cross-sections, Plates IX. to XII, and in the elevation, Plate III. From them has been taken very nearly one-half of the ore extracted from Ruby Hill.

Connection of ore bodies with depressions in the quartzite.—As has been stated in Chapter IV., many of the ore bodies in the Ruby Hill mines are intimately connected with sags or depressions in the quartzite; and the manner of formation of these basins was there described. That large ore bodies should be of frequent occurrence in these depressions is not strange when it is remembered that the limestone in them was in a shattered and crushed condition, and that the quartzite, with its casing of clay, served to a certain extent to confine the metal-bearing solutions to this limestone mass, where large quantities of those solutions were probably allowed to settle quietly and deposit ore. It was in these basins that the conditions most favorable to ore deposition were found.

In the Richmond ground, although such depressions in the quartzite occurred in the upper as well as in the lower levels of the mine, they do not seem to have been accompanied by ore bodies, in spite of the fact that the character of the limestone was favorable to ore deposition. This can be accounted for by several facts. The two main ore channels in the Richmond mine, the east and west ore bodies, did not approach the quartzite, owing to the fact that the fissures with which they were connected did not

lie near that rock in the portion of the mine above the water level. There is, moreover, a large block of undisturbed ground, which has already been described, page 32, and which in a measure separates the west ore body from the crushed limestone near the quartzite. It is difficult to tell exactly how this undisturbed ground deflected the ore solutions, but it is likely that it was one of the principal causes of the arrangement of the ore bodies. There are large blocks of ground in the upper levels of the Richmond mine, near the quartzite, which have been incompletely explored, and it is by no means improbable that new ore channels may be revealed and important ore bodies may be discovered by careful prospecting in that direction.

CHAPTER VII.

THE SOURCE OF THE ORE.

Theories in regard to the formation of ore deposits.—One of the most important inquiries connected with the geology of the Eureka District relates to the source of the ore, for a successful solution of this problem would afford information valuable in the search for further deposits, besides possessing great scientific interest. A discussion of the various theories which have been held in regard to the formation of ore deposits in general, some of which might be found applicable to the Eureka deposits, cannot find a place in this report, but it may be well to mention the only solutions of this problem which are in any way warranted by the facts which have been observed. These are: First, a deposition of the ore in small particles simultaneously with the limestone, the ore being afterward segregated into nearly isolated bodies, either by chemical or mechanical action; second, a segregation of the ore in the limestone from the country rock on either side of it; and, third, a deposition from solutions which came from below.

Relative time at which the minerals were deposited.—Although the periods at which the different minerals which compose the ore bodies were brought into their present position may have been separate and distinct, it is highly improbable that such has been the case, and it is not likely that some of them should have been segregated from the country rock, and others either have been washed in from above or brought up in solutions from below. Evidence against this last supposition is not plentiful in the oxidized ore masses, where the original position of the ore has often been changed by the flow of underground streams, although it can still be found in the least disturbed portions of them. But in the undecomposed sulphuret ores there is clear proof that the various minerals were deposited simultaneously. They occur irregularly, but in about the same relative proportions throughout the mass; they show no signs of concentric structure or of successive deposition, and although this is not positive evidence that their sources were the same, yet

it is difficult to conceive of a derivation from different sources without a difference in the time of deposition, which would necessarily result in a variation in the character of the ore.

Metals contained in the country rock.—There is a sharp distinction between the composition of the ore and that of the inclosing rock. Iron oxide forms the gangue of the ore bodies, and about one-half of the ore is composed of that mineral, the other portion being made up of lead, arsenic, sulphur, zinc, silver, carbonic acid, etc. The first four of these substances do not seem to occur in the least metamorphosed limestone, and only appear in the more altered limestone in small bunches and seams in the neighborhood of ore bodies. There is a large block of stratified limestone on the sixth level of the Richmond, which is very little altered, and it shows no evidence of ever having contained any quantity of the metals enumerated above. It is hard, compact, and crystalline-granular. It is distinctly stratified, and has been comparatively little disturbed. The highly-altered limestone, on the other hand, contains notable quantities of some of these metals.

Ratio of the ore to the limestone.—As close a calculation as possible has been made of the relative proportion of ore to limestone, in order that some idea may be formed of what percentage of the metals that rock must have originally contained if the ore had been uniformly distributed in small particles throughout its mass. The ratio of the limestone to the ore extracted from that portion of the mineral zone situated between the main fissure (the Ruby Hill fault) and the contact fissure, between the quartzite and limestone in the ground southeast of the Richmond shaft, is about 100 to 1. In the mineral zone northwest of this shaft the ratio of limestone to ore is somewhat greater. If a reduction of one-half is made for large bodies of low-grade ore which up to the present time would not warrant extraction, and for yet undiscovered masses, of which it is but reasonable to suppose there are some in existence in the portion of the mineral belt southeast of the Richmond shaft, the ratio of the limestone to the ore would be 50 to 1. Putting the assay value of the ore at $40 in gold and silver to the ton of 2,000 pounds, and the percentage of lead at 10 per cent., which cannot be regarded as too high when all the ore which has been removed from the mines is taken into account, then each ton of limestone must originally have contained 80 cents in value of the precious metals and 0.2 per cent. lead.

Amount of silver in the country rock.—Among all the assays of country rock made only one over 50 cents was obtained, and that was in the immediate vicinity of a large ore body, near the sixth level of the Richmond mine. The farther from an ore body a sample is taken the poorer as a rule is the limestone, as will be shown hereafter when the assays are examined in detail. Fifteen cents in silver is a remarkably high assay to be got from stratified limestone. That rock lying near the shale outside of the main fissure contains scarcely more than a trace of the precious metals. Suppose the

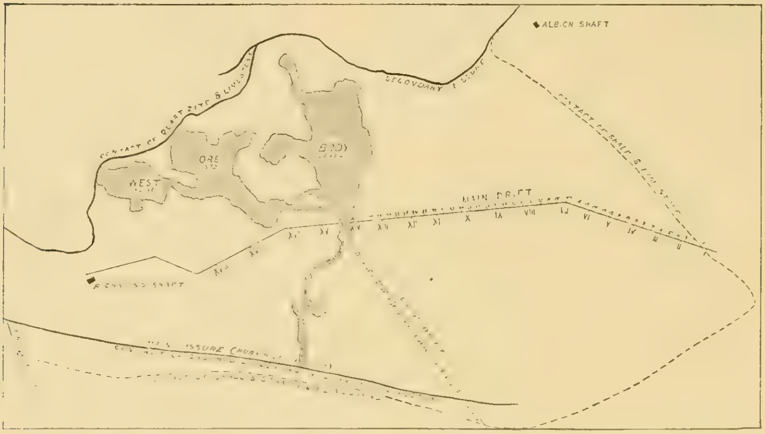


FIG. 2.—Plan of main drift and cross-drift, 600-foot level, Richmond mine. Scale, 400 feet=1 inch.

calculation made above to be incorrect, and let the possible value of the limestone be reduced to one-half, or 40 cents, this amount would still be very considerably in excess of the average value of even the crushed and most altered rock, and very much greater than the highest assays obtained from unchanged limestone.

Assays of country rock.—With a view to determining, if possible, whether the ore was derived from the surrounding limestone, or whether the limestone was impregnated with ore from the ore bodies or the solutions to which they owe their origin, careful assays were made of the limestone on two lines leading up to a large ore body, the lowest portion of which was about 30 feet above the sixth level of the Richmond mine. Since these assays

were made the continuity of this ore chute with but a few breaks has been established nearly down to the ninth level. The preceding diagram, Fig. 2, explains the positions of the ore bodies and their relations to the country rock.

First series of assays.—The Arabic numerals on the main drift refer to the numbers of the first series of samples which were taken for assay. The positions on the drift from which the samples were taken are marked by black dots. The samples were taken every 25 feet, and the subjoined list describes the character of the rock and its assay value in silver.

LIST No. 1.

No.	Description.	Assay value.	Averages.		
		Cents.			
1	Blue shale	6			6
	BLACK STRATIFIED LIMESTONE.				
2	Yellowish broken limestone	9			
3	......do	34	18⅔		
4	......do	13			
5	Black, hard, compact, stained limestone	10		[a] 12⅗	
6	Same blacker	12			
7	Same somewhat foliated	14	13		
8	......do	16			
	CRUSHED BROKEN LIMESTONE.				
9	Broken friable white limestone	12			
10	Broken friable sparry limestone	25			
11	Broken friable black limestone	15	15⅘		
12	......do	14			
13	Broken friable yellowish-black limestone	13			
14	Broken friable white limestone	10			
15	Same darker	10			
16	Broken friable brownish limestone	14	15⅕		
17	Broken friable blackish limestone	16			
18	Broken friable highly crystalline limestone	26			
19	Same more compact	13			
20	Friable white limestone	18			
21	......do	11	14⅗	13.88	
22	Compact white limestone	16			
23	Broken friable white limestone	15			
24	......do	10			
25	......do	12			
26	Same more compact	9	10⅗		
27	......do	11			
28	Broken friable white limestone	11			
29	Same compact	21			
30	......do	12			
31	White and black limestone with yellow spots	13	13⅕		
32	Same sparry	10			
33	......do	10			

[a] See page 86.

List No. 1—Continued.

No.	Description.	Assay value.	Averages.
	BLACK STRATIFIED LIMESTONE.	*Cents.*	
34	Compact crystalline black limestone	8	9 2/5
35	Compact crystalline white stained limestone	13	
36	Compact crystalline black limestone	8	
37	......do	10	
38	......do	8	
	BLACK BROKEN LIMESTONE.		
39	Broken black limestone	15	19 1/2
40	Broken yellowish stained limestone	15	
41	Broken reddish stained limestone	18	
42	......do	30	

Second series of assays.—The Roman numerals on the northeast side of the main drift correspond to another set of samples which were taken in the same drift at the designated spots. This second set of samples was taken in order that a comparison might be made between the assay values of the limestone and the electrical phenomena observed by Dr. Barus at the same points. They are only given here that as many assays as possible may be brought to bear on the question of the impregnation of the limestone, and will be referred to in more detail when the results of Dr. Barus's work are examined.

LIST No. 2.

No.	Description.	Assay value.	Averages.
		Cents.	
I	Blue shale	6	6
II	Slightly stained black stratified limestone	11	11 1/2
III	Same less stained, with calcite	12	
IV	Broken friable white limestone	7	10 7/9
V	......do	10	
VI	......do	12	
VII	Same slightly stained	10	
VIII	Same very white	9	
IX	......do	10	
X	Same brecciated and slightly stained	12	
XI	Broken friable white limestone	12	
XII	Broken brecciated limestone stained black	15	
XIII	Reddish stratified limestone	10	10
XIV	Black broken stained limestone	65	27 4/5
XV	White broken stained limestone	20	
XVI	......do	27	
XVII	Same slightly stained	10	
XVIII	Black stained limestone	17	

Third series of assays.—A third set of samples marked with dots and numbers on the diagram was taken from the cross-drift, and the result of the assays with a description of the samples is annexed.

LIST No. 3.

No.	Description.	Assay value.	Averages.
		Cents.	
1	Blue shale	5	5
	STRATIFIED LIMESTONE.		
2	Grayish limestone	6	
3	Hard black limestone, with calcite and red spots	15	9
4	do	6	
5	Grayish limestone	9	
	BROKEN AND CRUSHED LIMESTONE.		
6	Crushed black limestone, with calcite	15	
7	Same more broken and stained	30	$16\frac{3}{4}$
8	White brecciated limestone slightly stained	10	
9	Same, but softer	12	
10	Same as No. 8	15	
11	Compact calcite slightly stained	20	$17\frac{2}{4}$
12	White crushed limestone	22	
13	do	13	
14	Bluish broken limestone, with calcite	15	
15	Same more broken	11	$13\frac{2}{4}$
16	do	16	
17	Grayish, very much broken limestone	12	
18	Similar, but pulverized	51	
19	Similar, but bluish	32	$32\frac{2}{4}$
20	Yellow and reddish soft broken limestone	23	
21	Bluish, somewhat broken	24	
22	Same more broken	15	
23	do	15	16
24	Bluish stained limestone	6	
25	Same more broken and stained	28	
26	Hard white sparry stained limestone	6	
27	Soft yellowish broken limestone	20	$19\frac{1}{3}$
28	Soft, taken near No. 14 of List No. 2	32	

Discussion of assays.—None of the specimens of limestone assayed contained any ore, at least none that was perceptible to the eye, and they had the appearance of the ordinary limestone found in the mineral belt. The assays, which were made with great care in the manner described in Chapter XI., prove: First, that the country rock near the ore bodies is richer in silver than that at some distance from them; second, that the least changed and metamorphosed limestone is the poorest; and, last, that the most crushed and broken limestone, and that which is somewhat stained with

ferric oxide, is usually the richest. There are several exceptions to be noticed in these specimens, but they do not seem to be sufficient to affect these general results. Although it has not been possible to fix with certainty on any particular variety of limestone which is to be regarded as the poorest, or richest, its contents in the precious metals bearing no very definite relations to its physical properties, yet it is usually possible to form some idea of the value of a piece of rock from its appearance, the crushed and stained varieties being usually the richest. It will be noticed that the specimens taken on either of the lines leading up to their junction below the large ore bodies do not show a gradual increase in value as the ore is approached. The want of regularity in this increase is owing to the facts that there is no uniformity in the character of the limestone, and that there appear to be zonês of rich and poor rock crossing the course of the main drift and cross-drift. The existence of such zones cannot be fully established by the number of assays that were made, as the limestone is constantly changing, and a rich piece and a poor piece are often found side by side; still the variations of certain groups of assays from the general average indicate that such zones exist.

Sample No. 3, in the first list of assays on the main drift, shows 34 cents in silver. This is an extraordinary amount to be obtained from limestone within the stratified zone, but although other samples were taken from the same spot no second such assay was obtained. It is abnormal, and it would have been struck from the list had it not been deemed proper to give the assays exactly as they were taken, although in reckoning the average assay value of the stratified limestone (Nos. 2, 4, 5, 6, 7, and 8) it has been omitted, as the other samples which were taken afterwards in the same spot were less than the average ($12\frac{2}{6}$ cents).

The average of the next five samples, from 9 to 13 inclusive, which were taken from the crushed limestone, is $15\frac{4}{5}$ cents. The stratified and crushed limestones are separated by a fissure which may have been the source of impregnation of the zones on each side of it. At any rate the averages of five samples decrease down to the fourth lot assaying $10\frac{3}{5}$, when they begin to increase again up to No. 34, which is in the next zone of stratified limestone. The average value of this zone of stratified limestone

is only $9\frac{2}{5}$ cents. The four samples, 39 to 42, inclusive, are in the broken limestone just below a large ore body, and their average is $19\frac{1}{2}$ cents. The samples which are marked on the map with Roman numerals do not show any remarkable changes until No. 13 is reached, which was taken from near No. 42 of the other list. It assayed 65 cents, and an average of nine other samples taken in the drift southeast of this point showed $17\frac{4}{9}$ cents. These samples were not far removed from ore bodies. Although the samples in list No. 3, taken in the cross-drift, do not show a uniform increase in metallic contents as the ore is approached, yet they indicate that the rock in the neighborhood of the ore is the richest on the average. The stratified limestone which lies outside the main fissure in this drift averages but 9 cents. The shale is invariably of low grade, the highest assay obtained being only 6 cents.

Results.—From the foregoing facts it will be seen that it is scarcely possible that the ore bodies could have been formed by segregation from the surrounding limestone. Had such been the case all the metals composing the ore bodies would have been found in appreciable quantities in the least changed limestone. The assays prove moreover that the silver in this rock was in all probability an impregnation accompanying the deposition of the ore bodies and was not an original constituent of the limestone.

Segregation from the limestone.—If the ore had been collected in its present position by segregation of any kind, there would have been innumerable places in which minute clusters and bunches would have been formed, and the limestone, instead of being perfectly barren or practically so for great distances in all directions, would have exhibited here and there at least signs of ore. The large caves and pipes are not the only openings to be found in the mass of limestone. There are openings of every size and shape; vuggs, small holes, drusal cavities, open cracks, and fissures are of frequent occurrence throughout the ore-bearing zone as well as in the limestone which has not been found to be productive, though the last has not been sufficiently explored to prove that these openings are as common as in the above-mentioned zone. That some of the cavities referred to may have been formed since the deposition of the ore is very possible, but it has been shown already that most of the fissures and cracks were produced

before the formation of the ore bodies. Had segregation taken place at all, it must have taken place throughout the mass of limestone; and it is very difficult to conceive of metal-bearing solutions or ore in any other form traversing hundreds of feet of limestone, offering every opportunity for the deposition of ore, and passing across fissures in such a manner as to leave no trace of their passage in many of the openings which must necessarily have been in their course, if they were derived from the country rock; yet this is what must have occurred, if the theory of segregation were applicable. Had the ore been segregated, it is probable, too, that there would have been no well-defined boundary between the country rock and the ore. Such is not the case, however. The ore is as definitely cut off when it comes in contact with the limestone as if it had been shoveled or rammed into the caves and openings. The limestone is often impregnated with ferric oxide in the neighborhood of ore chambers, but the dividing-line between the ferruginous limestone and the ore is very plain. The limestone at a distance of 6 inches from very rich ore often shows no signs of iron or of anything else that would indicate the proximity of ore.

Segregation from the shale.—The shale nowhere carries more than a trace of silver and gold, and what has been said in regard to a segregation from the limestone applies also to the shale. Indeed, it is still more improbable that metal-bearing solutions should have been uninterrupted in their passage through the clay of the Ruby Hill fault and should not have been concentrated on its hanging-wall side. A derivation of the ore from the shale is, therefore, inadmissible.

Segregation from the quartzite.—Silver, gold, lead, and some other minerals have been found in small quantities in the quartzite, but ores were never obtained from the latter rock in paying quantities, and occurred chiefly in small seams and fissures. It has been explained that there has been considerable motion of the quartzite upward against the limestone along a fissure, and that this fissure contains a great deal of clay and was of prior origin to the ore bodies. What has been said in regard to mineral solutions traversing the clay of the main fissure is equally true in this case. A segregation of ore from the quartzite is, therefore, hardly among the possibilities. Neither is it possible to suppose that the ore was introduced from above, for none

of the rocks which may have covered the present surface contain any heavy metals.

The manner in which the ore entered the limestone.—The evidence in regard to the actual source of the ore is rather of a negative than of a positive character. The theory of segregation is untenable; and other theories, such as that of a deposition in beds simultaneously with the country rock or of an infiltration from above, are not to be thought of. The only reasonable explanation which can be given of the source of the ore, and the only one which is not contradicted by the observed facts, is that the ore bodies were formed by infiltration from below. It has already been shown that the ore chambers are intimately connected with fissures. Some of these—for instance, the main fissure, as exposed on the twelfth level of the Eureka, in the cross-cut to the Locan shaft—evidently served as channels for ore-bearing solutions, and it is extremely probable that most of them at one time or other have carried mineral solutions to the ore bodies. All fissures are more or less connected with the two principal ones, and many of the ore bodies are also connected together, and they have in general a downward trend. All the facts point to an ascension of the solutions, and these solutions were in all likelihood a result of the solfataric action consequent upon the eruption of rhyolite.

Cause of the solfataric action.—It has already been stated that there is a strong probability, if it is not absolutely certain, that the eruption of rhyolite preceded the deposition of ore. Extensive eruptions of this rock took place at no great distance from the mines, and, as has been described, a dike of it follows one of the chief fissures of the mineral zone. The decomposition of this dike and of other rocks accompanying it, especially the quartz-porphyry, is such as is characteristic of volcanic regions, and its occurrence must almost inevitably be ascribed either to the rhyolite eruption or to the still more recent outburst of basalt. There is no basalt, however, either in or near the mines, and therefore nothing to indicate a connection between its ejection and the deposition of ore. The solfataric action traceable in the mines is therefore most naturally referred to the rhyolite eruption. It is of course no objection to this hypothesis that the rhyolite is itself decomposed, since the decomposition of lavas within a few days of their ejection, by the gases and solutions of the same eruption, has frequently been observed; while

the period of the rhyolite eruptions near Eureka may have covered centuries. The character of the decomposition of the rhyolite is familiar, and consists largely in the extraction of the heavy bases and alkalies, leaving siliceous clay as a residue. Sulphureted hydrogen is almost invariably an accompaniment of volcanic action, and the alkalies in solution were in part converted thereby into sulphides. As most of the sulphides of the metals are soluble in solutions of the alkaline sulphides, a vehicle was thus formed for the transportation of any of those metallic sulphides which might be present. Those sulphides, or compounds which would yield them, might have formed constituents of the rhyolite.

Rhyolite as a source of the ore.—As a matter of fact there is no rhyolite in the immediate vicinity of the ore which contains sufficient gold, silver, or lead to admit of its being regarded as the source of these minerals in the ore. It is barely possible, though not likely, that the rhyolite body of which the dikes in the mines are the upward continuation, may have carried a notably larger percentage of heavy metals than that now to be found in a fresh state on the surface. In fact, near the mines, it is almost completely decomposed, and it cannot be obtained in a tolerably fresh state above ground at considerable distances from the workings.

Quartz-porphyry as a source of the ore.—The rhyolite is not the only eruptive rock met with in the mines. Quartz-porphyry also occurs, but only in the neighborhood of Adams Hill. This rock, however, contains considerable quantities, relatively speaking, of gold and silver, particularly of the former. The explorations in the mines in which it is found are not sufficient to give any definite idea of its extent, but it is possible that it is much more extensive than its croppings suggest. The result of the assays made of this porphyry, which are described in the chapter on assays, indicates that this rock contained silver and gold, and perhaps lead, after it solidified and before any solfataric action could have affected it. Though the age of the quartz-porphyry cannot be proved from this district, there can be no doubt, from its lithological character and its mode of occurrence in innumerable other localities, that it is pre-Tertiary and far older than the rhyolite. That the solfataric action incident to this eruption had an effect upon this porphyry is extremely probable; at any rate, changes of a solfataric character were

brought about in it, such as the formation of iron pyrite and the concentration of gold and silver in that mineral from the porphyritic mass. Moreover, although it is not certain that the gold, silver, and lead in the mines in its immediate neighborhood were derived from this rock, yet the amount of gold, silver, and lead it contains, and the transformation it has undergone, render it a possible source of these metals in the ore of the mines of Adams Hill. The mines of Adams Hill, which are mentioned in another portion of this memoir, are many of them noted for the large proportion of gold to silver found in their ores. As regards the mines of Ruby Hill, which are separated from those of Adams Hill by an intervening belt of shale, it cannot be stated as anything more than a possibility that their ore was derived from the decomposition of the quartz-porphyry.

Granite as a possible source of the ore.—It has already been mentioned (page 12) that granite probably underlies the sedimentary rocks of Ruby Hill, and perhaps those of the whole district. This rock has but one small outcrop. It has been carefully assayed, but only a trace of silver and no gold has been discovered in it. The only place where specimens could be obtained was on Mineral Hill, and they were all much decomposed. It is nowhere exposed in the underground workings, although bowlders resembling granite have been found in the quartzite near the bottom of the Richmond shaft. It is only natural to expect that this decomposed granite should show very little of the precious metals even if the undecomposed rock originally contained perceptible quantities. Investigations which have been made of massive rocks carrying gold and silver have always shown that the decomposed varieties were invariably poorer in these metals than the unaltered rock, except where enriched by infiltration.

Source of the ore in Prospect Mountain.—With reference to the deposits of Prospect Mountain, which are almost identical with those of Ruby Hill, it can be stated that although there is no quartz-porphyry or any other massive rock carrying perceptible quantities of gold and silver in its immediate vicinity, yet there is no proof that such rocks do not exist in depth in or near the ore-bearing formation, and that, as such rocks have been found on Adams Hill in connection with ore deposits, it is possible that they may have been the source of the ore in that region as well.

Conclusions.—The results of the chemical and physical examinations which have been made of the rocks of Eureka have been rather negative than positive as regards the source of the silver. They have shown what rocks have not been the source of the ore more conclusively than they have proved its origin. They seem, however, to point in but one direction, namely, to some massive rock which has been decomposed by the solfataric action attending the eruption of rhyolite. Through the decomposition of this rock metal-bearing solutions were formed which afterward penetrated the limestone and deposited the ore

CHAPTER VIII.

MANNER OF THE DEPOSITION OF THE ORE.

Derivation and circulation of the metalliferous solutions.—In the foregoing chapter it has been stated that the ore was probably derived from some massive rock by solfataric action. The solutions containing the ore penetrated the limestone, passing through fissures and interstices in the broken rock, and deposited the ore where conditions of temperature, pressure, and chemical activity were favorable to its precipitation. The irregularity of the deposits and their connection with fissures and other phenomena have already been described and accounted for, but as yet no attempt has been made to explain the causes which led to the release of the minerals from the solutions which contained them and their aggregation in immense chambers. It is impossible to determine what may have been the chemical composition of these solutions, but it is not improbable that they consisted in great part of sulphides of the heavy metals dissolved in alkaline sulphides. These solutions were necessarily formed under the influence of heat and pressure. Rising into the shattered limestone at a diminishing pressure and temperature, the liquids lost much of their solvent power and many of the metals that they contained were precipitated.

Manner in which the ore was deposited.—As to the manner of this precipitation, two theories only are admissible, either that the ore was precipitated from the solutions in pre-existing large openings, or that it was substituted directly for the limestone, that rock being dissolved and metallic minerals being left in its place. In other words, the ore was either deposited in caves and other openings, or the caves found above the ore bodies were caused by a shrinkage of the ore and the action of dissolving waters.

Importance of the manner of deposition.—At first sight this question does not seem of great practical importance, for if the mineral-bearing solutions came

from a considerable distance below, and it is highly probable that they did, it would be reasonable to suppose that the deposition would continue as far as it would be possible to follow it. An investigation of the phenomena attending the formation of these deposits will show, however, that the manner in which the ore was deposited has a very important bearing upon the probabilities of finding ore at any considerable distance below the water level.

Theory of the formation of caves.—The formation of caves in limestone is usually attributable to the action of waters percolating from the surface and carrying carbonic acid in solution. As is well known, even rain-water contains carbonic acid in solution, though in small quantities corresponding to the traces of carbonic anhydride always present in the atmosphere. The air occupying the pores of the soil for a considerable distance from the surface is much more highly charged with carbonic anhydride than the free atmosphere, a fact no doubt due to the oxidation of organic matter, and the percolating waters are correspondingly charged with carbonic acid. Below the permanent water-level of a limestone country the water is nearly saturated with calcium carbonate, and though there is a slow circulation of subterranean currents beneath this level no strong local action can be expected. To form a cave at a given spot, water containing free carbonic acid must be supplied in sufficient quantities, and an escape must be provided for the more or less saturated solution of calcium carbonate which results from the corrosion of the rock. Caves cannot, therefore, form at an indefinite depth from the surface of the limestone under any circumstances, for, after passing a certain distance through limestone, the percolating waters would be nearly or quite saturated. Caves, too, can only be found in a country with deep drainage, since otherwise the saturated solvent could not be removed.

The rate of cave formation is dependent upon the quantity of water, the amount of carbonic acid that it contains, and the velocity with which it flows. Climatic changes and changes in the formation from dynamic causes accelerate or retard the action of these waters as the case may be, but a tendency to the formation of caves exists wherever water percolates through limestone. The solution of limestone ordinarily appears to be accompanied by the deposition of more or less calcium carbonate in the

same neighborhood. When the processes of solution and deposition go on simultaneously their coexistence is no doubt due to local differences of temperature and pressure. Changes in the amount of percolating water and other circumstances may also bring about deposition where solvent action once prevailed, or *vice versâ.* As before stated, the dissolving of the limestone in particular directions has been owing in great measure to the antecedent crushing of the limestone.

Connection of caves with fissures, ore bodies, and each other in Eureka.—The caves in Eureka District are of more frequent occurrence near the surface than they are in depth, no caves of any importance having been found below 1,000 feet. They are almost invariably connected with some fissure, and are also often connected with one another by fissures and open pipes. No oxidized ore body of any great magnitude is found without a cave above it, which is usually proportionate in size to the ore body, but all caves are by no means accompanied by masses of ore. Though the caves are very irregular, having ramifications in all directions, they form a system or systems which have a downward trend approaching the foot wall of the formation in which they are found. As the ore bodies are associated with caves their deposition is, of course, similar.

Action of water in the caves.—The roof and sides of the caves sometimes present the appearance of a chamber blasted out of the solid rock, and do not show any signs of the action of water. This, however, is rarely the case, and is a result of the falling in of the roof and sides as they were originally formed. The action of the water can often be observed upon some of the sides of the bowlders, which in such instances always cover the bottom of the caves. Usually the surfaces of the caves show the effect of the corroding action to which they have been subjected; the rock is hollowed out in cup-like forms, which are roughened and indented with lines caused by the difference in solubility of the various parts of the rock. These surfaces have a light-grayish color streaked with white, and in the neighborhood of ore are more or less stained with ferric oxide.

Formation of aragonite and calcite in the caves.—Clusters of aragonite and calcite crystals are frequently found covering large areas on the roof and sides. Although water is found dripping from the roof of some of these caves it

never accumulates in any considerable quantity on the floors, but the atmosphere is always damp. The growth of aragonite crystals is not confined to the roofs and sides of the caves, bowlders which have fallen from the roof often being covered with them. Whether these crystals are of stalagmitic origin or whether they owe their formation to exudations from the floor is uncertain, but the latter supposition seems the more likely, for although drops of water were seen falling from clusters of aragonite crystals in the roof no corresponding aggregations were noticed where the drops struck below. The caves above ore bodies do not differ in any respect from those in which no ore is found, and although they may have been formed at a different period there is no reason to suppose that they owe their origin to a different cause.

Connection of caves with the outer air.—That some of these caves are connected together by openings, and that they have connection with the outer air, is proved by the fact that in many of them there is a very decided draught of air, although they may be several hundred feet below the surface. In some instances this draught is so strong that a lighted candle held near contracted openings leading to the caves is extinguished.

Depth to which the cave formation extends.—From the foregoing, it appears that the cave formation in general does not extend to any very considerable depth and that its limit in Eureka is probably reached within a thousand feet. If the theory of a simple crystallization of minerals from solutions in pre-existing caves were correct, it is evident that the practical limit of ore deposition would be reached at the point where cave formation was no longer possible. This would naturally be the point where the carbonic acid solution, being saturated, ceased to dissolve limestone. In Eureka, the limit of the cave formation is probably reached in less than a thousand feet, or before the water level[a] is attained, as in the Richmond ground between the 7th and 9th levels there are several partially open fissures which, although they show that considerable water has passed through them, nevertheless do not exhibit anything like the same amount of corrosive action which is everywhere apparent in the upper caves. The struct-

[a] In speaking of the water level, reference is had to the mines of Ruby Hill, those of Prospect Mountain not yet having reached that depth.

ure of the fissures is plainly visible, and the bowlders in these are angular, showing that they have not been much attacked by water.

Arrangement of the ore in the chambers.—During the investigation of the Eureka deposits, upon which this report is based, several favorable opportunities were offered for examining freshly-discovered ore bodies of considerable size. In two of these cases the ore was discovered by following seams stained with ferric oxide. The two places mentioned were above the ninth level of the Eureka and below the sixth level of the Richmond. The ore was struck in both instances considerably below the caves which formed the apices of the chambers. The ore in the lower part of the chambers, if not in what could be called a solid state, was at least in a much more compact form than it was in their upper portions. It had the appearance of being in place, that is to say, that of being in the position which it originally occupied when deposited from solutions. With the ore composing the upper portion of these ore bodies it was otherwise; this was in a loose state and often distinctly stratified, the strata being composed of different varieties of ore. There was frequently a layer of gray carbonate of lead, followed by a yellow one composed of a mixture of ferric oxide and plumbic sulphate, with here and there, through the whole, bunches of galena surrounded by its products of decomposition.

In the Richmond ore body a small cavity in the ore-mass was observed containing stalactitic columns of minerals, which were evidently formed by crystallization from solutions. The layers of ore were covered by layers of sand and gravel and bowlders which formed the bottom of the caves. The whole upper portion of this mass showed clearly that it was brought into its present position by water, and the stratification of the ore proved that it was deposited in its present position since oxidation took place. There were layers of the miners' yellow carbonate, composed of every shade of yellow and brown, which, although some of them were not a sixteenth of an inch thick, were as distinctly defined and as clearly visible to the eye as any layers would be in a piece of shale of unquestioned sedimentary origin. The planes of stratification were rarely horizontal, and this was not remarkable, as a large mass of loose ore in a cave of irregular shape and with inclined sides would not settle in a uniform manner, and the strata

would be more or less bent. Moreover, water carrying fine particles of ore in suspension, trickling slowly down over an irregularly-inclined surface, would not deposit the particles in horizontal layers, but in layers conforming more or less to the inclination of the bed in which it flowed. This stratification is common enough in the upper part of ore bodies, and is occasionally met with in the lower portion, though it is, of course, most apparent when the strata have been least disturbed by pressure. It is not meant that the ore throughout these chambers had a stratified appearance; on the contrary, the different ore-minerals seemed to be mixed throughout the mass without reference to any law of distribution. It sometimes appears as if there were more unaltered galena in the lower portions of ore bodies than in the upper, but the difference, if any exists, is so slight that it is not of much importance. In large ore bodies the ore is much more compact at the bottom than at the top, which may be accounted for by the difference of pressure. The limestone surrounding ore chambers is frequently stained with iron. This seems to be less common in the upper part of the caves than it is lower down. The staining of the limestone is often observed where seams are found leading to ore bodies or where separate masses are connected together, as is often the case, by small pipes.

Evidences in the ore of pseudomorphism after limestone.—In many of the ore bodies which have been discovered strong evidence has been found that a portion of the ore is pseudomorphous after limestone, or, in other words, that it has been substituted for that rock. A mass of ore sometimes contains a rounded bowlder of limestone as a nucleus; a great deal of the ore, when it has not been stratified or pressed into a compact mass, exhibits the form of crushed and brecciated limestone. Small masses of ore sometimes completely fill the spaces between the limestone walls; are perfectly solid, and show clearly that they have not been disturbed since they were deposited. If these deposits had been formed by the crystallization of minerals from solution they would have exhibited, notwithstanding their oxidation, the banded structure which is everywhere supposed to be an accompaniment of this manner of deposition. Although the deposits first described are oxidized to a great extent, the change in their chemical nature would not have been sufficient to obliterate all traces of structure from their mass. Pseudo-

morphs of galena after calcite have been observed at Andreasberg and in other mines. Had they been found at Eureka, it is scarcely probable that they would have remained recognizable, in view of the subsequent oxidation of the ore. It is probable, however, that calcite crystals were not formed until after the period of ore deposition, and it is, therefore, in no way remarkable that the search for pseudomorphs after calcite was unsuccessful.

Relation of the rhyolite eruption and the caves to the formation of ore.—The disturbance incident to the rhyolite eruption caused the faulting and crushing which prepared the limestone for the circulation of the metal-bearing fluids. It is not likely that the waters carrying carbonic acid had effected any material dissolution of the limestone before an opportunity was given for their free circulation by the shattered condition of the country. If the deposition of ore is correctly referred to solfataric action consequent upon the rhyolite eruption, the precipitation of the sulphurets may have begun immediately after the outburst of volcanic rock and before a sufficient period had elapsed to allow of the formation of caves. Besides the caves above ore bodies, there are many cavernous openings in the limestone in which no ore occurs; but some of these empty caves, as has been mentioned, are connected by open fissures or pipes with ore bodies. Had these caves existed at the time of the deposition of ore, it is difficult to see why they failed to receive a share of the deposits. Although this is not absolute proof that these caves were made after the ore was deposited, it is entirely consistent with such a theory.

If the caves had been formed first, they certainly would have contained gravel, bowlders, etc., washed in by water or representing insoluble residues, and this material would have been found underlying the ore. This, however, is not the case; the ore is very free from admixtures of foreign substances, and wherever this detritus is found, it either overlies the ore or occupies a position adjacent to it, consistent with the hypothesis of subsequent placement. If the caves were not formed after the deposition of the ore, they must necessarily have been enlarged during the oxidation of the sulphurets, for this can have been sustained only by supplies of oxygen carried by water from the surface. This water must have held carbonic acid in

solution and must have attacked the limestone. It is true that in many caves the ore has the appearance of having been placed in the cup-shaped cavities which are so common and which were evidently formed before the ore came into them; but it must be remembered that much of the ore, especially in the upper part of the caves, has been brought into its present position by water.

Partially formed caves and ore chambers.—In a portion of the ground already described, between the seventh and ninth levels of the Richmond mine, there is a great deal of open country; there are no caves, however, and it does not often show signs of the action of surface waters. The ground is shattered and there are large fissures which are filled for the most part with bowlders and fragments which have fallen into them. Around some of these bowlders ferric oxide and ore are found, but these masses are not of any great size. Some of the fragments are rounded off as if ore had been substituted for their exterior parts, and the whole mass presents the appearance of an ore chamber, the formation of which had been interrupted. From the seventh level a distinct ore channel can be traced up to the west ore body as well as downward to the ninth level.

Effects of oxidation on the bulk of the ore bodies.—The chemical reactions which took place when the ore was substituted for the limestone are unknown, but from observations made in small masses of oxidized ore resulting from the decomposition of sulphurets, that were evidently formed by substitution, it would seem that the ore replaced the limestone very nearly bulk for bulk; that is to say, very nearly though not quite filled the space originally occupied by the limestone. In the masses referred to there were no signs of the vigorous action of water carrying carbonic acid, and the walls were compact; therefore it is not likely that these bodies had been disturbed since the ore was deposited as sulphurets, and it is probable the slight shrinkage of the masses was due to oxidation. In the large chambers, where there is a cave directly over the ore body, the size of this cave has usually, but not invariably, borne a direct relation to the size of the ore body, a large cave being followed by a large mass of ore. This would indicate that the cave owed its origin in a measure to the shrinkage of the ore. Whether the ore shrinks or expands in oxidizing is a point which depends upon its composition.

Were the ore composed entirely of pyrite it would shrink on oxidizing. Although the hydrated oxide of iron occupies molecule for molecule more space than the pyrite, yet the quantity of iron left in place after the oxidation of a mass of pyrite is not equal to the amount of that metal that the pyrite originally contained, owing to the fact that in the process of oxidation soluble salts are formed which are carried off. To the action of such soluble salts is no doubt due the staining of the limestone with ferric oxide in the neighborhood of ore bodies. On the other hand, if the ore were composed entirely of galena it would increase in bulk when changed into carbonate, though the carbonate of lead is to some extent soluble in waters carrying carbonic acid.

Observations made in a mass of pyrite.—From what has been observed of a mass of pyrite containing but a little blende and galena on the eleventh level of the Eureka mine, it would appear that oxidation is followed by a slight shrinkage of the ore body. This body of mineral is a compact mass which seems, as far as explorations have developed it, to touch the limestone everywhere throughout its surface. The pyrite, however, is separated from the limestone by a coating of ferric oxide nearly a foot thick. The ferric oxide contains grains and rounded fragments of limestone, and by its structure shows that the pyrite from which it was derived was brought into place by substitution. Pseudomorphs of pyrite after calcite are well known, although no specimens have been observed in Eureka; pseudomorphs of pyrite after fragments of limestone, however, are often found on Ruby Hill. The ferric oxide is also much more porous and less compact than the pyrite. A shrinkage of the mass took place upon the leaching which followed oxidation.

Evidences of the contraction of ore bodies since oxidation.—As pyrite originally composed more than half the volume of the ore bodies, it is highly probable that a considerable contraction has taken place in their mass since oxidation began. Supposing such a decrease of volume to have been brought about by oxidation, an opening would be produced above the ore body proportioned to its size, as the ore becoming porous would naturally settle by its own weight. Add to this the action of surface waters carrying carbonic acid, which would enlarge these cavities and to some extent redistribute the ore, and a condition of things is brought about precisely similar to that which at

present exists in the large ore chambers. In the unchanged ore bodies, which are encountered occasionally near the water, there is nowhere any evidence of the banded structure characteristic of the simple crystallization of minerals from solution. The galena, blende, and pyrite of which these ore masses are principally composed are distributed in bunches and compact masses, and nowhere is there any evidence of paragenetic order. It is true that a paragenesis of minerals is traceable in many places in the oxidized ore, but this is due to successive stages of decomposition.

Description of the Raibl deposits.—Attention has been already called (Chapter VI.) to Raibl, in Carinthia, where galena and zinc deposits occur in a limestone formation. Pošepný,[a] who very fully describes these deposits, mentions the following facts: The galena deposits occur principally in the dolomite, and the zinc deposits in the underlying limestone. They are to be classed neither as beds nor as lodes. As to the genesis of the ore, they differ very widely; the galena deposits were made in pre-existing cavities in the dolomite, while the zinc ore is pseudomorphous after limestone, or, in other words, was brought into its present position by substitution for country rock. The proofs this author gives of the manner of formation of the lead deposits are very conclusive. The ore, which consists principally of galena, blende, pyrite, and dolomite (cerussite, smithsonite, calcite, and barite being comparatively uncommon), is deposited in concentric layers, the cavities being sometimes completely filled, though often an empty space is found at the center, and hardly admit of a doubt in regard to their being formed by crystallization from solutions. The occurrence of a peculiar tubular galena ore (Röhrenerz), which was formed around pre-existing stalactites of dolomite, effectually establishes the fact that the cavities existed before the ore-bearing solutions made their appearance. As regards the manner of their formation, the zinc deposits are widely different from those of lead. The ores composing them are zinc bloom, smithsonite, calamine, and mixtures of these minerals with manganese and iron oxides, different kinds of iron ores, and peculiar clays. The calamine is seldom found

[a] F. Pošepný. Die Blei- und Galmei-Erzlagerstätten von Raibl in Kärnten. Jahrb. der k. k. geologischen, Reichsanstalt. Wien, 1873, B. xxiii.

except in the dolomite, and the smithsonite is the principal zinc ore in the limestone.

Pošepný's conclusions.—It is not necessary to give a detailed description of the specimens of zinc ore from which Pošepný concludes that these deposits are pseudormorphs after limestone. Suffice it to say that the zinc minerals have very often precisely the same structure as the original limestone, and that many pieces have been found in which the thin veins of calcite in that rock are continued in the form of smithsonite in the adjoining zinc ore. In some few places in the mineral zone the galena-blende deposits have undergone decomposition, and galena, blende, and calamine are found together. Pošepný gives the priority of formation to the galena-blende deposits, as at some points where decomposition has taken place and a portion of the ore has been removed part of the space has been filled with calamine. He further says that the calamine is probably the product of the decomposition of the blende, and that the zinc deposits themselves were formed by the substitution of zinc carbonate for calcium carbonate. From the fact that the galena-blende and the zinc deposits in Raibl are formed each in a different manner, this author regards it as probable that in the regions of Upper Silesia, Belgium, and Sardinia, where these two kinds of ore occur in the same deposits, they owe their origin to the same different causes which brought about their deposition in Raibl.

Comparison of Raibl and Eureka.—Although the Eureka ores do not contain a very large amount of zinc, either as blende, calamine, or smithsonite, yet numerous specimens of calamine have been found in the oxidized ores which exactly correspond with the pseudomorphs after limestone which Pošepný describes, and which were evidently formed directly or indirectly by substitution for limestone. Whether the zinc was originally substituted for the limestone as blende, and afterwards oxidized to calamine, or whether it was oxidized first and in the form of a solution attacked the limestone, is uncertain, but it is probable that it was deposited as silicate from a solution, as examples of other secondary minerals in the form of stalactites and stalagmites are not uncommon in druses in the oxidized ore bodies. The inferences which Pošepný draws regarding the deposits of Upper Silesia, etc., from those of Raibl, are certainly not applicable to the Eureka ores.

The internal structure of the ore masses in no way resembles those of Raibl. Where the ore is not oxidized there are no signs of a banded or concentric structure, and the phenomena observed point entirely to substitution of the sulphurets for country rock.

Some of the ore bodies formed by substitution.—The unoxidized ore bodies have not yet been sufficiently explored to establish the fact that they were formed in toto by substitution, but sufficient evidence has been obtained to prove that a considerable portion of the ore at least was deposited in this manner. In the cases of the Upper Mississippi, and those of Missouri, the galena is found in the form of stalactites and stalagmites, which proves the pre-existence of the openings, but in Eureka no such case has been noted.

Evidence against the substitution theory.—There is one argument to be advanced against the theory that the ore bodies were formed exclusively by substitution, namely, that some of the ore chambers are far removed from what seems to have been their most natural course. It has been remarked that in the mines southeast of the "compromise line" the ore bodies are of rare occurrence near the Ruby Hill fault-fissure, except when the two fissures approach in the deeper workings. The ground in the neighborhood of this fault presents all the conditions necessary to the fulfillment of the phenomena of substitution; it is crushed, shattered, and broken in various ways, and is traversed by cross-fissures. The lines on which ore is found gradually approach the quartzite foot wall, and correspond almost exactly with what would have been the natural channels of surface-waters descending through fissures. If the caves were not formed before the ore, why did the ore solutions not follow other channels apparently offering equal facilities for the substitution of ore? No satisfactory answer has been found for this question, but it is manifest that mine-workings, however extensive, never fully expose the system of underground fissures, and it is entirely possible that a barrier to the passage of solutions in this direction existed which has not been brought to light. Even had ore been deposited only in pre-existing openings, traces of lead minerals should have been precipitated in the interstices of this broken ground if it was accessible to metalliferous solutions, but none such could be discovered.

Preponderance of evidence in favor of the substitution theory.—Weighing the evidence on both sides of the question, it appears that a large part of the ore was brought into its present position by substitution, while it seems impossible to demonstrate that any part of it was deposited in pre-existing caves. It is highly probable that all the ore was deposited by substitution, and that future developments will effectually establish the fact. There is no reason for believing that, if the physical conditions favorable to the deposition continue below the water level, deposits of ore will cease to be found below that point.

Age of the ore.—In the Ruby-Dunderburg mine, on Prospect Mountain, there is a rhyolite dike similar to that of the Jackson and Phœnix. In all of these mines ore has been found in contact with and below the rhyolite in the limestone, but has never been found on the opposite side of it. This fact alone would not necessarily prove that the dike is older than the ore bodies, for these might occupy their present relation to it in consequence of a fault; but the manner in which the ore is deposited on the rhyolite, showing no signs of having been disturbed, and the fact that the rhyolite does not in any place contain inclosed fragments of ore, though it often contains country rock, go to prove that the eruption occurred before the deposition of the ore and that it did not fault the ore bodies. Another fact tending to prove the subsequent formation of the ore is the extreme decomposition of the rhyolite through the ore-bearing region, which was no doubt brought about by chemical action attending the deposition of ore.

Although it has not been established beyond doubt that the rhyolite eruption caused the upheaval which made the main fault on Ruby Hill, yet it is extremely probable that such was the case. It has been shown that this fault was the last dynamic disturbance of any importance that occurred in this region, and nothing is more natural than to connect it with the latest volcanic outburst in its neighborhood. If the Ruby Hill fault was formed by the rhyolite eruption it is likely that the rhyolite was injected into it at the time of its occurrence. The ore solutions seem to have entered the limestone through the main fissure after its formation and not simultaneously with it. And it may be inferred that the ore solutions owe their genesis to the solfataric action following the ejection of that eruptive rock. As the

rhyolite eruption covered a considerable period it is not improbable that there have been overflows of that rock since the beginning of the ore deposition at some point in the district. As the rhyolite eruption occurred in the Tertiary it follows that the ore formation was not of an earlier date. The solfataric action to which this region was once subjected has long since spent itself, and there is nothing to indicate that the increment of heat is abnormal.

CHAPTER IX.

WATER.

Water in Prospect Mountain.—The deepest shaft on Prospect Mountain, the Atlas, the working shaft of the Ruby-Dunderburg Company, has attained a depth of over 800 feet, and up to that depth but little water has been encountered. In the other mines in this part of the district no water of any consequence has been met with, and from the great altitude of many of them above the valley no trouble on account of water need be expected for some time to come.

Water in Ruby Hill.—On Ruby Hill, the water question is becoming a very important one, and in the future the difficulty of draining the mines may prove a serious impediment to exploration. The water now stands just below the 1,050-foot level in the Richmond shaft, but in the old workings of the Eureka it rose to the twelfth level, 220 feet above this point, before the cross-cut from the 1,200-foot level of the Locan shaft cut the Ruby Hill fissure. The surplus water from the twelfth level of the Eureka flowed down a winze to the Richmond ninth, and finally reached a permanent level at about 1,050 feet. A reference to the water line on Plate III. shows that the water level in the mines on Ruby Hill is highest at the southeast end or where the limestone wedge is the smallest, and that it gradually declines until, in the Richmond ground, where the limestone is the widest, it stands in the Richmond shaft at a point 650 feet below the water level in the incline of the Phœnix. It will thus be seen that the water from the southeast end of the mineral belt gradually finds its way into the Richmond; that is to say, that it has a tendency to flow in that direction, though owing to the fact that the workings of the mines are not everywhere connected in the lower levels the water does not follow an uninterrupted course.

This is not surprising when the nature of the ground is taken into account. The two fissures, which are everywhere accompanied by a thick casing of clay, meet at a point much nearer the surface in the Phœnix, the line of junction gradually descending as the Albion is approached. This line of junction corresponds very nearly with the water level, showing that the closing in of the two fissures forms a sort of flat funnel which debouches in the Richmond mine. The water level in this mine is something below the level of Diamond Valley, where the Eureka Cañon enters it. It has already been mentioned that there is a considerable zone of fissured ground in the lower levels of the Richmond. This broken ground naturally permits a tolerably free circulation of the water, and as the water level in this mine is about what it would be in the upper part of Diamond Valley it is reasonable to suppose that a permanent water level has been reached in the Richmond. Irregularities in the distribution of water are often brought about by the intervention of blocks of unfissured ground, or by the presence of clay seams. An illustration of this was given by the occurrences observed in a drift from the 1,200-foot level of the Richmond shaft. This shaft was comparatively dry down to a depth of 1,230 feet. The last 500 feet were sunk in quartzite. At 1,200 feet a cross-cut was started through this rock to the north. No water that could not be easily handled with bailing tanks was encountered, and when the limestone was penetrated it was found to be nearly dry, the water from the quartzite being excluded by the clay. In driving a short drift to the northeast from the main cross-cut, however, a stream of water was struck which became unmanageable without the aid of pumps, and it rose to near the 1,050-foot level, and at this point it has remained, notwithstanding the large flow of water that there has been from the Eureka mine. This Eureka water, however, did not flow down the shaft, but into a winze which was sunk on what appears to be the fissure of the Ruby Hill fault. The ground near this fissure is much shattered, and the disappearance of the water goes to prove that this condition continues to some depth.

Water in the Locan shaft.—In the Locan shaft, which has now attained a depth of over 1,200 feet, it had always been possible to control the water, which was first encountered at a depth of 700 feet, with the hoisting

machinery with which the shaft was equipped even while sinking to the 840-foot level. When this level was reached a cross-cut was driven to the old workings with which connection was made just above the twelfth level, a little over 1,000 feet below the top of the Lawton shaft. The water from the Locan shaft was allowed to flow along this cross-cut and enter the twelfth level, where, joining with the other water on that level, it was conducted to the "water winze" on the Richmond ninth.

Shortly before this report was finished, pumping machinery having a capacity of 600 gallons per minute was completed at the Locan shaft and sinking was continued. Stratified limestone and shale were struck at a depth of 1,020 feet. The stratification of this bed was nearly horizontal, and at a depth of over 1,200 feet the shaft had not penetrated it. A southwest cross-cut was run from the 1,200-foot station to the main fissure, a distance of 300 feet. The first 60 feet were in shale and the rest in a mass of limestone mixed with clay, which is the product of the Ruby Hill fault. The fault fissure contained ore, and when it was cut by the drift a body of water was developed which soon filled the cross-cut in spite of the pump. The flow of water was so sudden that the men had barely time to escape from the drift. It rose to a height of 1,035 feet in the shaft (about 50 feet above the water level in the Richmond), and up to the present time (December, 1883) it has not been possible to materially lower it.

The flow of water from the shale was not as great as from the limestone above it, the shale acting as a barrier. It will be observed that before the large body of water was struck in the end of the cross-cut from the 1,200-foot level of the Locan shaft, the water rose in the shaft to the 840-foot level, and ran into the twelfth level of the old workings, but after the fissure was cut it only rose to 1,035 feet, or about the upper surface of the shale. The fact that the tapping of the main fissure partially drained the twelfth and thirteenth levels, shows that there was a water channel between these levels and the point at which the vein was cut on the 1,200-foot level of the Locan shaft, and as this water, as well as that which drained into the shaft from the limestone overlying the shale, would not rise higher than 1,035 feet, a level which is but a few feet higher than the water level in the Richmond, it would appear that there was a water channel also along

the main fissure between the place where the vein was struck in the 1,200-foot Locan cross-cut and the Richmond ground. This is made all the more probable by the fact that although the Richmond received the water of the Eureka in the manner mentioned on page 51, yet the water level in the "water winze" of the former mine was not materially altered.

Prospects of water in the future.—Although this flow of water has not been controlled by the present pumping machinery, it is unlikely that it is of such an extent that more powerful pumps would not exhaust it. It must be borne in mind that the lower belt of shale cannot but act, partially at any rate, as a barrier to the flow of water from the upper limestone, and, therefore, it is but reasonable to expect that the flow of water in the lower limestone will not be uncontrollable. This has been indicated in a measure by the fact that the limestone encountered in the cross-cut on the 1,200-foot level of the Richmond was at first nearly dry, and the water that was afterwards struck on the same level was not present in such quantity that a pump like the one at the Locan shaft would not easily have managed it. It is very likely that the contact of the quartzite and limestone will be the principal source of the water, and for that reason it is to be avoided as much as possible.

CHAPTER X.

DO THE RUBY HILL DEPOSITS FORM A LODE?

Difference of scientific opinions on this subject.—On this subject there appears to have been a great difference of opinion. In the celebrated lawsuit between the Eureka and Richmond mining companies, which was argued before Justice Field, of the United States Supreme Court, Judge Sawyer, of the ninth United States circuit, and Judge Hillyer, for the district of Nevada, in July, 1877, a large amount of expert testimony was offered by both parties. Messrs. T. Sterry Hunt, W. S. Keyes, R. W. Raymond, T. J. Reid, and I. E. James testified in favor of the Eureka that in their opinion the zone of limestone included between the quartzite and the shale[a] was a lode in the miner's sense of the term; whereas Messrs. Clarence King, J. D. Hague, J. D. Whitney, William Ashburner, and N. Wescoatt declared it as their opinion that neither from a practical nor a scientific point of view could the above mentioned belt of limestone be regarded as a lode, and denied the existence of a stratum of shale in the position mentioned by the other experts.

Causes leading to the suit.—The Richmond company had been following down a body of ore which had been developed in the Richmond and Tip-Top inclines and terminated in the Potts chamber, which lay partly in the ground claimed by both companies. The so-called "compromise line" had been established, after a former trial, as a boundary between the properties of the two companies, and it was the prolongation of this line, or rather of a

---

[a]This shale was variously referred to by the Eureka experts as clay and shale. In the Eureka ground the clay was supposed to be a thin belt of shale which had been flattened out by pressure and decomposed. By some it was believed to be a continuation of the same body of shale which existed on the surface and below in the Richmond mine. It is, in reality, a rhyolite dike in the Jackson and Phœnix.

perpendicular plane passing through this line, that the Eureka company claimed as the limit of their ground. In order to establish their claim it was necessary that the Eureka should prove that they possessed a lode, or, at any rate, a mineralized zone within the meaning of the United States mining laws. The Richmond company, on the other hand, claimed the whole of the Potts chamber, inasmuch as they had a right to follow their body of ore, as developed in the Richmond, as it passed into the Eureka claim beyond the extreme northeasterly point of the compromise line as it was originally established. This body of ore, which was continuous, or very nearly so, from the surface down to the deepest workings of the mine (at that time about the ninth level), followed a fissure or system of fissures for nearly the whole distance. Sometimes the ore was found on the lower side of the fissure planes, sometimes on the upper, the fissures frequently expanding into an ore body. The course of the fissures was about N. 45° W. On the other hand, the Eureka company followed an ore body lying on the quartzite from some distance above the end of the fifth level down to below the seventh. From this point ore was traced to the body at the end of the ninth level which connected with the Potts chamber.

There was considerable difference of testimony in regard to the continuity of the ore-connection between the Eureka seventh and ninth levels. In some places it consisted of iron oxide carrying but a small amount of gold and silver, which was found along the quartzite.

In view of the existence of a secondary fissure between the quartzite and limestone, which the investigations forming the subject of this report have proved, this ore-connection was a valid one. The Eureka and Richmond, therefore, each established the existence of a lode leading into the Potts chamber from their respective claims. The former claimed that their lode extended from the quartzite to what they called the shale (the clay of the Ruby Hill fault or main fissure), and the latter that their lode was wholly in limestone and had no connection with either quartzite or shale.

Decision of Judge Field.—The court decided that the belt of limestone between the quartzite and shale (as understood by the Eureka people) constituted a lode in the sense of the law of 1872 and the usage of miners, and that, therefore, the portion of the Potts chamber situated southeast of the exten-

sion of the compromise line belonged to the Eureka company, as a vertical plane passing through the compromise line, and its extension was, by virtue of the agreement between the two parties, the boundary of their individual rights; moreover, that the Richmond company could not follow the ore outside of a vertical plane passing through their end line.

Decision of the United States Supreme Court.—The case was carried to the United States Supreme Court, on appeal, and the decision of the lower court was sustained by Chief Justice Waite, upon the ground that the agreement effected between the two parties in 1873 gave all ground situated on the northwest side of a vertical plane passing through the compromise line to the Richmond company and all that lying to the southeast of this plane to the Eureka company, and that the conditions under which this compromise was made necessitated the prolongation of this plane across the mineral zone. Chief Justice Waite did not state whether, in his opinion, this mineral zone between the quartzite and shale or clay constituted a lode or not.

Summary of the physical characteristics of the mineral zone.—Beginning at the extreme southeastern corner of the plan of contacts (Plate III.), a belt of limestone is visible which Mr. Arnold Hague has determined as Cambrian, and to which he has given the name of Prospect Mountain limestone. This limestone extends in a northwesterly direction nearly to the Albion shaft; is bounded on the southwest by a mass of quartzite, also Cambrian, and on the northeast by a belt of stratified limestone and shale belonging to the same period. These three formations, which all dip to the northeast, were originally laid down one upon the other at the bottom of the sea and afterwards raised above water at the close of the Carboniferous. At some period subsequent to their upheaval and prior to the deposition of ore, a deep and extensive fissure and fault cut through these formations. Its course was about northwest and its dip about 70° to the northeast. For the present purpose, it can be taken as extending from one end of the plan of contacts to the other. It can be seen near the surface southwest of the American shaft, in the Jackson, Bell-shaft and Utah tunnels, and in a short incline beyond the Richmond mine office, and may be visible in other places. It no doubt could be traced for the whole distance exposed on the map if trouble were taken to remove the débris from the rock in place. This fissure is exposed in numerous places underground and its inter-

section with the quartzite is laid bare in the deeper workings of all the mines except the Richmond and Albion. It is accompanied by an auxiliary fissure between quartzite and limestone which joins it below.

Conditions below the junction of the two fissures.—Where the two fissures come together in all the mines southeast of the compromise line the ore has been found filling the fissure between the quartzite and the limestone, or between the quartzite and the lower belt of shale. Whether this will continue to be the case as the fissure is followed downward is a matter of speculation. It is likely, however, that when the lower wedge of limestone widens out the ore bodies will take on their usual irregular character, although they will be no doubt in some way connected with the fissure to which they owe their origin.

Conditions northwest of the compromise line.—The change which takes place in the Richmond ground soon after the compromise line is passed has been fully explained. The two ore chutes, called, respectively, the west ore body and the east ore body, have the complexion of two distinct lodes in limestone. Whether the Potts chamber, which forms a part of the east ore body, actually touched the quartzite or not is uncertain, but, at any rate, it was within a few feet of it. This ore body, however, does not approach the quartzite in any other place. The west ore body touches the quartzite in the Eureka ground near the compromise line, but in all other parts of the mine occupies a position about midway between the secondary fissure on the quartzite, and the main Ruby Hill fault to the northeast. As these two fissures are gradually coming together, and, no doubt, meet at greater depth, it is evident that if these two ore chutes continue down they will eventually form the filling between the two fissures. From the present appearance of the ground it would seem as if the ore-channel which fed the east ore body was near the compromise line, and that it was on the main fissure which is exposed in the winzes from the seventh, eighth, and ninth levels of the Richmond near that line; and that the source of the ore of the west ore body was the system of fissures which branch out from small ore bodies, extending from the sixth to the ninth levels near the A C line. The fact must not be overlooked that there is a connection between these two ore chutes along the quartzite in the Eureka ground; that is to say, there is a fissure with ore in it here and there. It is, however, impos-

sible to state with certainty what the original ore channels may have been. No doubt many cracks, fissures, and vents through which the ore-bearing solutions passed have been completely closed since the ore was deposited, and it is likely that in many such openings the ore has left very little trace of its passage. When the openings were small, these solutions would naturally pass with considerable velocity, and little or no ore would be precipitated.

The immense pressure of the surrounding rock would be sufficient to completely close many ore channels. The ore that has been exposed in the Albion mine is a continuation of the Richmond west ore body, and nearly the same conditions prevail in this part of the hill as in the Richmond.

Discussion of the meaning of the words "lode," "horse," etc.—In a word, the main fissure and the secondary fissure branching from it inclose between them a mass of limestone which is penetrated in many places by crevices. The ore bodies occur within the limestone mass and are all connected with the fissure system just described. The ore bodies are usually lenticular or irregular in form, but sometimes follow the fissures as tabular masses. What name is to be given to this occurrence, though no doubt important from a legal point of view, is a verbal rather than a scientific question. There are portions of it to which no one has hesitated to apply the name of lode or vein.

In the usage of English-speaking miners the terms vein and lode are nearly but not quite synonymous. A vein may or may not carry ore, for it is perfectly correct and entirely usual to speak of a vein of calcite or other barren mineral, a connection in which the word lode could not be applied. In reference to ore deposits, lode is not used to denote the filling of very small fissures, for a stringer might be called a vein of small size, but scarcely a lode. It is most often used to indicate the contents of more complex fissures, or as synonymous with composite vein, system of veins, etc., while the term vein, with qualification, usually refers to the filling of fissures of a simpler character. Thus in the early days of the Comstock the two main branches of the deposit were known as the "east vein" and the "west vein," while the whole system was called the Comstock lode. So, too, Henwood says:[a] "The wider parts of *lodes* rarely consist of veinstone only, but inclose also blocks of the adjoining (*country*), and thus assume a brecciated structure. Their widest portions often (*take horse*) split, but such separate veins are seldom rich."

[a] Metalliferous Deposits, p. 84.

As there is an unquestionable connection in depth between the various ore-bearing regions of the Ruby Hill deposits, if this nomenclature is correct the ore bodies are to be regarded as branches of a single lode. Nevertheless, the fact is that these deposits differ essentially from those which yielded the usually accepted definition of the words vein and lode, and the analogies between the two varieties are so distant that an attempt to apply the terminology of typical veins to the Ruby Hill deposits as a whole leads immediately to misunderstandings. In ordinary veins ore is deposited in pre-existing openings, while the bodies of Ruby Hill were mainly deposited by substitution. In ordinary veins nearly all the space not occupied by fragments of rock is filled with ore and other minerals. In the Eureka occurrence many of the fissures have served merely as channels for the solutions, and space for deposition has been provided mainly by chemical means. The bearing of those differences is readily made apparent. In typical lodes a fragment of country rock entirely inclosed within the fissure, and hence completely and substantially surrounded by ore and gangue minerals, is called a "horse," but a mass of rock divided from the surrounding country by mere cracks not filled with vein matter is not called a horse.

The term "horse" is usually unequivocal and signifies a mass of country rock of considerable size entirely inclosed in ore or vein matter. One can always conceive, however, of the croppings of a vein being eroded to the level of the center of a horse, one surface of which would then be exposed to the air, and the horse would not be entirely inclosed by ore and gangue. Masses of rock in the croppings of a lode when they resemble horses in other respects are therefore known by the same name. No definite limits can be assigned to the size of a true horse, which certainly depends upon the size of the lode as well as upon individual opinion. Nevertheless, although there are horses in the Comstock lode a few hundred feet wide, it would be a most extraordinary lode that would contain a horse exceeding 1,000 feet in width, and the limestone wedge of Ruby Hill is much wider than that on the surface. All miners will probably agree that a horse must be a portion of the contents of a vein or lode.

In the mineral zone of Ruby Hill many masses of rock are surrounded by fissures, most of which are mere fault seams, though some of them have

been no doubt the channels of ore-bearing solutions. These masses in ordinary veins might have been surrounded by vein matter, but, owing to the peculiar manner in which ore was deposited in this locality, the surrounding fissures do not often show ore. These masses of rock then take the place of horses from a structural point of view, but do not answer the current definition of the term, and a misunderstanding or an error is involved either in calling them horses or in denying their structural analogy to horses. If it were once admitted, however, that a mass of rock not substantially inclosed in ore or secreted gangue minerals may be called a horse whenever the fissures by which it is divided from the solid country belong to an ore-bearing system the consequences would be serious, for a horse is always regarded as a part of the fissure filling, as a portion of the vein or lode, and the lode would then necessarily be coëxtensive with the fissure system. In that case the term lode would be synonymous with mining region. The quicksilver belt of California would be a single lode, as, too, the California gold belt, and the great Arizona and Utah mineral zones would each represent a single complex vein.

Classification of ore deposits according to different authors.—Such an extended signification of the words lode and horse would also be wholly at variance with any system of the classification of ore deposits which has hitherto been adopted, for these depend to a very great extent upon the external form of ore bodies. Von Cotta says:[a] "I divide all ore deposits primarily according to their form into regular and irregular. The former fall into two groups, beds and veins; the latter into stocks and impregnations." In the next paragraph he says: "A single aggregation of ore may consist of several separate deposits of different forms." These passages make it as clear as possible that von Cotta regarded a substantially regular tabular form as essential to a vein, and when ore masses of different shapes are so associated as to imply a simultaneous and common origin he would relegate them to different classes without regard to the community of origin. Since von Cotta, two eminent mining geologists, Grimm and von Groddeck, have written important monographs dealing with the classification of ore deposits. Each has endeavored to give greater weight to genesis in classification than von Cotta did. The following table explains the classification of each of these authors:

[a] Erzlagerstätten, I., p. 2.

VARIOUS CLASSIFICATIONS OF ORE DEPOSITS.

Von Cotta (1859).	Grimm (1869).	Von Groddeck (1879).
I.—Deposits of regular form: 1. Beds. a. Metalliferous strata and coal. b. Placers. 2. Veins (gänge[a]). a. Ordinary veins (Quergänge[b]). b. Bed veins (Lagergänge[c]). c. Contact veins. d. Lenticular veins (Lenticulärgänge[d]).	I.—Ore-bearing strata [deposits in which the ore is an essential constituent of the country rock]: 1. Original disseminations. 2. Secondary disseminations. a. Placers. b. Ore-bearing bowlders.	I.—Primary deposits: 1. Stratified deposits. a. Compact ore seams. b. Seams with disseminated ore. c. Ore beds. 2. Deposits forming original portions of massive rocks. 3. Deposits forming the filling of cavities. a. Veins: In massive rocks; in stratified rocks. b. Cave fillings. 4. Deposits formed by metamorphism or substitution.
II.—Deposits of irregular form: 1. Sharply defined bodies (stocks[e]). a. Reticulated veins (Stockwerke[f]). b. Contact stocks (Contactstöcke). c. Cave fillings (Höhlenausfüllungen). d. Butzen.[g] e. Racheln.[g] f. Rinner.[g] g. Taschen[g] (pockets). h. Nester, Nieren[g] (nests, kidneys), etc.	II.—Separate deposits of ore [deposits in which the ore is distinct from the country rock]: 1. Tabular masses. a. Beds. b. Veins. c. Segregated zones. 2. Deposits of irregular form. a. Bedded masses. b. Masses independent of stratification.[e] c. Reticulated veins.	II.—Secondary or detrital deposits.

[a] The German word Gang comprises the English words lode, vein, and dike.

[b] Veins which cut the stratification of formations if the country rock is stratified.

[c] Veins between the strata of a formation which have been formed since the rock was deposited.

[d] Similar to gash veins, only not coming to the surface.

[e] Von Cotta makes a sharp division between ore and country rock a part of the definition of stock. Grimm calls bodies which pass over gradually into the country rock, as well as those which are sharply defined, stocks (Stöcke). Von Cotta also divides stocks into two classes—those that conform to the stratification of the country rock and those that do not.

[f] Von Cotta remarks that, strictly speaking, reticulated veins should not be classified as deposits of irregular form, but as the union of a great number of small veins; in other words, the included angular fragments are so large, compared with the width of the fissures, that they cannot be considered as horses.

[g] Von Cotta uses these terms to describe the local occurrence of various irregular ore bodies.

An examination of this table will show that the term lode as understood by these authors cannot be applied to the wedge of limestone between

the quartzite and the Ruby Hill fault. Prof. R. Pumpelly also has published, in Johnson's Encyclopedia, a classification of ore deposits according to which, however, the ore deposits of Ruby Hill as a whole would be as far removed from typical veins as in the other systems. Some of the ore bodies in the limestone wedge are well-defined veins, and when they connect with each other they can be considered as parts of the same lode.

Miners' definition of lode.—Nevertheless, it will be conceded that the miners' definition of the word lode, however indefinite it may be, has a much more comprehensive meaning. Dr. Raymond, in his testimony in the Richmond and Eureka lawsuit,[a] says: "The whole subject of the classification of mineral deposits is one in which the interests of the miner have entirely overridden the reasonings of the chemists and geologists. The miners made the definition first. As used by miners before being defined by any authority it [lode] simply meant that formation by which the miner could be led or guided. It is an alteration of the word lead; and whatever the miner could follow, expecting to find ore, was his lode. Some formation, within which he could find ore and out of which he could not expect to find ore, was his lode." The mining law of the United States as interpreted by the courts also gives a broader signification to the word lode

Necessity of a better classification of ore deposits.—The different definitions of the word lode have given rise to a great deal of discussion in the courts, and a classification of ore deposits which would reconcile the adverse views would tend to simplify the question for the miner, the lawyer, and the geologist. Mr. S. F. Emmons,[b] while introducing the classifications of Messrs. von Cotta, Grimm, von Groddeck, and Pumpelly, in his abstract of a report upon Leadville, Colorado, recognizes the necessity of a more satisfactory classification. He says: "That the difference of origin and manner of formation should be a more important factor in the classification of ore deposits than has been the case hitherto is generally admitted, but, owing to the fact that the definite determination of such origin requires more laborious and expensive investigations, especially from a chemical point of view, than geologists are in general able or willing to make, trustworthy data are as yet too meager to form a basis for a general classification from this standpoint."

[a] Supreme Court of the United States, Nos. 1058 and 1059, p. 210.
[b] Second Annual Report of the Director of the United States Geological Survey, p. 233.

CHAPTER XI.

ASSAYING.

Object of assaying country rock.—With a view to discovering, if possible, the source of the ore in the mines of Eureka District, numerous and careful assays of all the different kinds of country rock in the neighborhood of the ore bodies were made by the author. As the quantity of the precious metals contained in any of these rocks is extremely small, it was necessary to take unusual precautions in order to determine with any degree of exactitude the amounts of gold and silver present. Assayers do not ordinarily attempt to estimate with accuracy any values of either gold or silver less than one dollar to the ton (0.0001659 gold or 0.0026518 per cent. silver), and as the country rock of this district never contains so much as this, particularly delicate methods were required in the determination of the actual quantities of these metals.

Difficulty of obtaining pure lead.—One of the principal obstacles to be overcome in obtaining satisfactory results in the assaying of all rocks containing very small percentages of the precious metals, is the difficulty of obtaining a lead flux which does not contain very appreciable amounts of gold and silver. The purest litharge which it was possible to obtain from dealers contained from 10 to 50 cents of silver to the ton of 2,000 pounds (0.0002652 to 0.0013259 per cent.), and as it was necessary to use from twice to three times as much litharge as the weight of the material assayed almost all the silver obtained from assays of country rock made with such litharge came from the litharge itself.

Approximately pure litharge required.—At first sight it might seem possible to obtain correct results by assaying the litharge separately and deducting its value in silver from the value of the assayed rock. This is not practicable, however, for the litharge of commerce is not only argentiferous but of very

variable composition, and no mechanical method of mixing is sufficient to bring about the degree of homogeneity required. The smaller the relation of the silver in the rock under assay to the silver in the litharge the greater is the uncertainty arising from the argentiferous character of the flux, and unless the litharge is nearly pure it is impossible to discriminate between errors arising from this cause and those due to insufficiency in the time of melting, imperfect fluidity of the slag, and the like.

Quantity of reducing material necessary.—The weight of the lead button is dependent upon the amount of reducing material used in the flux and the amount of sesquioxides present in the rock, which it is necessary to reduce to protoxides, provided reducing gases be excluded. As there were no other sesquioxides than that of iron present, and this only in very small quantities, the weight of the lead button was not materially altered in that way. For reasons which will be given hereafter, it was found advisable not to use sufficient reducing matter to exclude all the oxide of lead from the slag.

Relation of the silver to the amount of lead reduced.—Experiments made with different quantities of reducing material upon the same flux showed that part of the silver in the litharge went into the button of metallic lead, while a part of it remained in the unreduced litharge in the slag. As might naturally be supposed, the proportion of silver to lead in the reduced button was always greater than in the litharge employed. The proportion of silver to lead also increased with the time during which the flux was kept melted and varied with the temperature and perhaps with other circumstances in such a manner that no law governing the proportions in which the two metals were reduced could be detected. When rich litharge, or litharge containing very appreciable amounts of silver, was used, it was therefore impossible to estimate with any sufficient degree of accuracy the amount of silver from the litharge which is united with that of the rock in the lead button. Even when the whole of the litharge is reduced, or as nearly as possible reduced, it is not likely that all the silver it contained is concentrated in the lead button, and it is only by using litharge (or any suitable form of lead) which contains little or no silver that it is possible to render the resulting error small enough to permit of estimating the probable amount of silver which the litharge gives up to the lead button.

Different kinds of lead.—White lead (carbonate of lead), sugar of lead (acetate of lead), and the best granulated lead ordinarily contain upwards of ten cents to the ton (0.000265 per cent.), and although any of them may be used in assaying rocks containing less than 50 cents to the ton (0.001325 per cent.), yet the results obtained are more or less uncertain, and are not at all to be relied upon in very poor rocks, such, for instance, as carry below 10 cents to the ton (0.000265 per cent.). Moreover, the carbonate of lead, owing to the carbonic acid it contains, is liable to boil over in the crucible, though this can be obviated by a previous calcining. A like objection can be made to the acetate, the acetic acid of which contains more carbon than is needed to reduce the oxide of lead. If it is used in its natural state it swells up, and after the acetic acid is decomposed the residual carbon thickens the slag and prevents the proper settling of the globules of lead which everywhere permeate the mass. This difficulty, however, can also be remedied by a previous calcining. Granulated metallic lead, though otherwise unobjectionable, melts too quickly and unites at once in a mass at the bottom of the crucible, thereby preventing every particle of the powdered rock from coming in direct contact with it; and although such an intimate contact is unnecessary in assaying ordinary ores, it is found indispensable where the material to be assayed contains such extremely small quantities of the precious metals as do the ordinary country rocks of a mining region.

Oxide of lead required in the slag.—It has been remarked that the slag is the better for the presence of oxide of lead. This is notably the case when the rock treated is silicious, as in combination with other bases it renders the silicate formed more fusible and liquid. Litharge seems also to attack quartz more energetically than even soda or potash. Even in those rocks which contain scarcely anything but carbonate of lime it is found to assist in the formation of a proper slag.

The process adopted for making litharge.—The litharge used in assaying all the Eureka rocks, as well as those of the Comstock, was made at the refining works of the Richmond Company in Eureka. The following process was adopted in manufacturing this litharge. One thousand pounds of market lead the refined lead obtained from the parting of silver and lead by the Luce &

Rozan method, containing about $1 to the ton (0.00265 per cent.), was cupelled on a fresh bone-ash test in an English refining furnace. The first 300 pounds of litharge resulting from this cupellation ran very poor, containing scarcely 2 cents to the ton (0.000053 per cent). The litharge which followed gradually increased in value until toward the last it contained nearly as much as the original lead. This last litharge was reduced by charcoal in a black-lead crucible, and the resulting lead was again cupelled, yielding an excellent quality of litharge. Upon reducing and recupelling the best litharge it was found that the percentage of silver was but little reduced, showing that a point can be reached in the process of desilverization at which it is not practicable to separate the silver from the lead by cupellation. The refined litharge also contained a trace of gold, but the quantity was so exceedingly small that it was neglected in the estimation of gold values in assays of single samples.

Assaying the litharge.—In assaying the litharge itself an interesting phenomenon was observed. If the litharge was mixed with sufficient charcoal to effect its reduction and the resulting lead was cupelled, it was found that a very much smaller quantity of silver was obtained than if the usual flux, consisting of bicarbonate of soda and bitartrate of potash, was used. To what imperfection in the process this is due is not clear. The proportional loss with ordinary litharge is much smaller than with that which contains extraordinarily little silver.

Experiments.—The following experiments illustrating the fact were made in duplicate, in order that the results might be conclusive: (*a*) 800 grains litharge were reduced with 600 grains bicarbonate of soda, 200 grains bitartrate of potash, and 200 grains borax. Silver resulting from cupellation, 6 cents per ton (0.000159 per cent.). (*b*) 800 grains litharge were reduced with 600 grains bicarbonate of soda and 200 grains tartrate of potash. Silver resulting from cupellation, 5 cents (0.0001325 per cent.). (*c*) 800 grains litharge were reduced with 30 grains powdered charcoal and 200 grains borax. Silver resulting from cupellation, trace. (*d*) 800 grains litharge were reduced with 30 grains powdered charcoal. Silver resulting from cupellation, trace.

Results.—From these experiments it will be seen that the largest amount of silver was obtained from the method employed in (*a*), and that the addition of borax increased the quantity of silver where charcoal was not used as the reducing agent. It is probable that the effect of the borax was merely a mechanical one, facilitating the settling of the minute particles of lead by rendering the slag more liquid, and that it had no reducing power on the silver in whatever form that metal may have been. In all these assays two hours were occupied in melting, and the lead buttons were cupelled at the lowest possible temperature.

Experiments in reducing agents.—Several experiments were made to determine the best reducing agents, and bitartrate of potash was found to give better results than any other. Upon the application of heat this substance is decomposed into carbonate of potash and carbon, both of which act energetically upon the substances to be reduced. Borax in the presence of strong reducing agents never takes up silver, even when it is used in considerable quantity.

Composition of flux.—The following is the composition of the flux used with 377.09 grains of the limestones of Eureka District:

	Grains.
Litharge	770
Bicarbonate of soda	580
Bitartrate of potash	165
Borax	400

With but slight modifications this flux answers for almost any country rock.

Weights used.—The weight adopted for the assays of the Eureka rocks, as well as those of the Comstock made for Mr. G. F. Becker, was 377.09 grains. Grains were employed instead of grams, as they correspond with the Oertling assay weights used with the latest improved Becker balance, and 377.09 of them were taken, as the .02-grain rider then represented 10 cents to the ton (0.000265) for every division of the balance beam. The values were calculated in cents to the ton of 2,000 pounds, as is usually the case on the Pacific slope, but they are also given in percentages.

Time and manner of melting.—In order to obtain the maximum results it was necessary to melt the assays for nearly two hours. This was accomplished

in a charcoal draft furnace, which would admit four No. 10 French crucibles at once. The fuel employed was charcoal made from the piñon pine, and it was scarcely inferior in heating power to coke. The heat was kept as nearly as possible at a point a little below the melting point of cast iron, and experience showed that after two hours the silver obtained no longer increased nor yet perceptibly diminished. With a higher temperature it may be that the time might be shortened, but taking into consideration the volatility of silver at high temperatures this expedient cannot be considered advisable. When the melting was less prolonged the maximum amount of silver was never obtained; indeed, in a series of careful experiments made to determine the best time of melting, it was found that some assays which had been kept at a melting heat too short a time, though thoroughly melted, yielded less silver than the litharge alone was known to contain.

Cupellation and cupels.—The lead buttons were cupelled in a small muffle furnace, the heat of which could be easily regulated, the fuel employed being also charcoal. Usually but two cupellations were carried on at one time and great care was taken to reduce the loss by cupellation to a minimum by keeping the heat at the lowest temperature consistent with the oxidation of the lead. In order that the heat should be maintained at the lowest possible point, the cupels used were made from one part of fine leached wood ashes and two parts of bone ashes. The ashes were those resulting from the burning of cedar wood, the most available wood containing little silica. The cupels were prepared in the following manner: The mold was filled with the requisite amount of the moistened mixture of the two ashes and the mass was pressed into shape by the punch. Then a coating of dry elutriated bone ash was spread over the top of the cupel, the punch again inserted and driven home. In this way a cupel was obtained which had great absorbing power, allowed the lead to be cupelled at an exceedingly low temperature, and because of its smooth surface prevented the small silver button from being engulfed in the coarse material of which the cupel was composed. The button, too, could easily be removed by the point of a knife without retaining any of the bone ashes.

Loss by cupellation.—Many experiments with a view to determining the loss by cupellation have been made by Hambly, Klasek, Plattner, and others;

but as the conditions attending this loss are dependent upon the quality of the cupel and the character of the furnace and fire, it is not possible to accept the results obtained by them as applicable in all cases. Some experiments upon the loss by cupellation were made for this investigation, as nearly as possible under the same conditions as those existing in the assays for the determination of small amounts of silver. It was found that when the temperature was not too high for feather litharge to form and when the draught was not too great, there was no perceptible loss of silver under .01 grain, which represents $1 to the ton of 2,000 pounds, notwithstanding that this .01 grain was cupelled with 400 grains of lead. In fact, in most instances, the button resulting from the cupellation of .01 grain or less of silver with 400 grains of lead weighed from 0.5 to 10 per cent. more than the actual amount of chemically pure silver cupelled with the lead. This excess is owing to the fact that the silver button obtained by cupellation is never absolutely pure, but always contains from 0.2 to 5 per cent. lead, as well as fine particles of the cupel. There is always a loss of silver in cupellation, but as this loss rarely exceeds 1 per cent. of the amount of silver present it can be entirely neglected in rocks containing less than $1 to the ton (0.00265 per cent.). This loss does not begin to be important until a value of over $10 to the ton (0 0265 per cent.) is reached. When the contents in silver is less than .01 grain, or less than $1 to the ton of 2,000 pounds, and the amount of lead alloyed with it 400 grains or less, the button resulting from the cupellation is invariably slightly in excess of the actual quantity of silver contained in the alloy. With amounts of silver exceeding .01 grain and lead exceeding 400 grains, up to a point where the quantity of silver does not exceed .1 grain, the weight of the button does not vary perceptibly, no matter what may be the quantity of lead (within reasonable limits) used. At first sight it would appear to be inexplicable that the quantity of lead did not to a greater extent affect the quantity of silver obtained, but it must be remembered that the greater part of the loss by cupellation takes place at the moment of "brightening," and that this loss is directly proportional to the quantity of silver present. It is also true that the greater the quantity of lead to be oxidized the greater is the loss of silver. But this latter loss is so small in comparison with the former

that it makes no perceptible difference whether 100 or 1,000 grains of lead are used with .1 grain of silver. It has been pointed out that the loss of silver is compensated for in small buttons by the lead retained and it would seem that this ought to be equally true of large ones, but as a matter of fact it is not, probably because large buttons remain for a longer time melted, thereby being more completely cupelled. As the silver contained in any of the country rocks of Eureka District scarcely ever reached 50 cents to the ton (0.001325 per cent.) the assays can be regarded as unaffected by any loss in cupellation. An experiment was made to test this inference, and it was found that there was no perceptible loss in cupelling 50 cents (.005 grain) of silver with 400 grains of lead at a temperature considerably above that required for proper cupellation.

Experiments.—In regard to the loss by cupellation in general the following experiments may be of interest as showing the differences in loss at various points in the muffle.

Nine assays, each containing 5 grains silver and 30 grains lead, were cupelled and the losses expressed in thousandths of the unit of 5 grains attending each, with the number of the assay, are shown in the diagram of the muffle in the position occupied by the corresponding cupel:

Back of muffle.

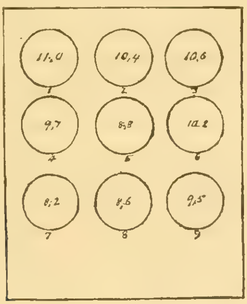


FIG. 3.—Position of cupels in muffle.

The order 9, 6, 3, 2, 8, 5, 7, 4, 1 represents the order in which the cupels were withdrawn from the muffle, and therefore the speed at which the cupellation took place. Nos. 7, 8, and 9 were cupelled at the proper temperature, but those in the back part of the muffle were too hot. It will

be observed that Nos. 9, 6, and 3 were finished first, showing that the draft on that side of the muffle was the strongest. The assay which showed the least loss was No. 7, which was in a position where the draft was the least and the temperature the lowest and where the cupellation occupied nearly the maximum time. The quantity of lead used with these assays was considerably more than was necessary for a proper cupellation. It was used in order to render the differences in loss as palpable as possible.

Six assays of 5 grains silver with 25 grains lead gave the following result:

Back of muffle.

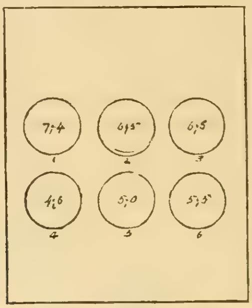


FIG. 4.—Position of cupels in muffle.

The order in which they were removed was 6–3–2–5–1–4; 5–1–4 being finished at about the same moment. Here, also, the draft was greatest on the right side of the muffle, and No. 4, which occupied the position of No. 7 in the former experiment, exhibited the least loss. The quantity of lead was still too great for perfect cupellation.

Two assays of 5 grains silver with 15 grains lead, cupelled side by side, gave a loss of 3.5 and 3.8 thousandths of the unit of 5 grains. This loss corresponds very nearly with that which Kerl[a] gives, and it is about as small as it is possible to render it.

Manner of removing buttons from cupels.—As many of the silver buttons obtained from the assays made of the Eureka rocks were so small that they could scarcely be discovered by the naked eye, it was found next to impossible to remove them from the cupel by raising them in pincers. Another method

[a] Bruno Kerl, Hüttenkunde, IV., p. 35. Leipzig, 1865.

was therefore resorted to. After they were loosened from the bone ash, the cupel was tipped up and the buttons were allowed to fall upon a polished steel anvil. When struck by a polished steel hammer any adhering impurities were removed and the flattened button was found sticking to the face of the hammer, from which it could be easily brushed into the scale-pan.

Manner of weighing.—In the Becker balance, used in weighing the silver buttons, the right arm of the beam is divided into twenty parts. If a rider weighing .005 grain is used each one of these spaces will represent .001 grain, and if a weight of rock equal to 377.09 grains is used in making the assays each one of these parts will represent 10 cents to the ton, or 0.0002652 per cent. By placing a card-board scale, on which each one of these parts is divided into ten, behind the beam and using a magnifying glass in front of it the position of the rider between any two of the points marked on the beam can be determined with accuracy up to one-tenth of the space, which would represent a value of one cent to the ton (0.0000265 per cent.). When new and in good order the Becker balance is sensitive up to .0001 grain, which represents a value of one cent to the ton. Allowing a difference of one cent (0.0000265 per cent.) one way or the other, it is safe to say that buttons can be weighed with almost absolute accuracy up to within two cents to the ton, or plus or minus one cent. As is well known, Harkort and afterward Plattner,[a] instead of attempting to weigh extremely small buttons, measured their diameters between two fine lines converging at a small angle, which were engraved on an ivory scale. Very small silver buttons are almost exactly spherical, and the method is therefore not only rational but calculated to give more exact results than weighing, but it requires very delicate manipulation to place the button so that both lines are exactly tangent to it. A common microscope with a micrometer eye-piece may be used instead of Plattner's scale, and the measurement made both more rapidly and more accurately. This method also obviates the necessity of removing the buttons from the cupel.

Inaccuracies of the results.—Admitting that the loss by cupellation is so small that it can be neglected, and that the method of weighing is correct within two cents, the other sources of inaccuracy attending the assaying of rock containing but minute quantities of silver are reduced to two, the imperfect

[a] Plattner's Probrikunst. Theodor Richter, p. 35; Leipzig, 1865.

reduction of the "pulp" and imperfect determination of the contents of the litharge. If proper care is taken in melting, most of the silver contained in the rock can be collected in the lead button. It cannot be expected that all the silver will be obtained, but what remains in the slag can be reduced to an almost constant quantity by reproducing in all assays nearly the same conditions, such as fineness of "pulp," length of time of melting, quantity of flux, etc. Assays of the same rock have been repeated several times with identically the same results. The quantity of silver produced after a certain point does not seem to vary perceptibly with the time during which the assay is kept melted. The second source of inaccuracy is the more difficult to control, namely, the impossibility of obtaining a flux absolutely free from silver, or of correctly determining the amount of silver in the button which is derived from that source.

Action of bitartrate of potash on litharge.—The quantity of litharge used in assaying Eureka rocks was about 770 grains. To reduce this litharge 165 grains of bitartrate of potash were added, and the resulting button of lead, when reducing gases from the fire had been excluded as far as possible, usually weighed in the neighborhood of 425 grains. Almost all the limestones in Eureka district carry more or less free carbon.[a] The quantity of sesquioxide of iron present was so slight that only a very small portion of the carbon was absorbed in reducing it to the protoxide (FeO.). Where there was any quantity of that mineral present in the rock it was necessary to increase the amount of bitartrate used in order to obtain a lead button of about 425 grains in weight.

Bearing of the silver in the litharge on the results.—The silver contained in the 425 grains of lead reduced from the 770 grains of litharge was 6 cents per ton (0.0001591 per cent.) when the flux itself was assayed. This amount scarcely ever varied, but frequent check assays were made. When peroxide of iron or other substances requiring reduction were present the weight of the lead button was less and the amount of silver it contained was also less. When other reducing substances were present, such as organic matter in the limestone, the weight of the lead was greater as well as the amount of the silver resulting from cupellation. This increase or decrease in the amount of silver

[a] This is particularly the case with the so-called "back limestone."

was, however, not proportional to the weight of the lead, as has been explained before. The difference, however, between buttons weighing 300 grains and those weighing 500 grains never exceeded 2 cents (0.000053 per cent.), and it is therefore safe to say that when the lead button did not vary more than 25 grains either way from 425 grains the possible difference could not exceed one cent (0.0000265 per cent.). Allowing 2 cents (0.000053 per cent.), or plus or minus one cent for inaccuracies in weighing, the total amount of all the possible inaccuracies can be reckoned at 3 cents (0.0000795 per cent.), or plus or minus 1½ cents.

Resumé of errors.—The possible errors in the silver assay as it has been described are the following: Inaccuracies in weighing the "pulp"; imperfect fluxing; insufficiency of the time of melting; impurity of the litharge; loss by cupellation; mechanical losses; and inaccuracies in weighing the silver button. All these errors, with the exception of those caused by silver in the litharge and the inaccuracies in weighing the silver button, are so infinitesimal, when the assay has been properly conducted, that they may be neglected altogether. The other two sources of error, the litharge and the balance together, cannot change the results more than three cents, and the influence of the latter of these can be very much reduced by the substitution of a microscope with a micrometer eye-piece for the balance.

Estimation of gold.—The determination of the amount of gold in any country rock where it is present in extremely small quantities is attended with great difficulties. It is scarcely ever as much in value as the silver and is always very much less in quantity. It is only by the concentration of a large number of assays that it can be determined at all, and the results even of this method are not always reliable. It is impossible to obtain litharge free from gold as well as silver, and it is much more difficult to determine its quantity or the effect that it has upon the assay. As nearly as could be determined, the amount of gold in the litharge used was about one cent to the ton of 2,000 pounds (0.0000016 per cent.). This result was obtained in the following manner: Twenty assays of the ordinary flux were reduced in the usual way, and the resulting lead buttons were separately cupelled until the lead remaining would weigh about twenty grains. The cupels were then removed from the fire and allowed to cool. The twenty lead buttons, which

collectively would weigh about 400 grains, were removed from the cupels and placed in a scorifier in the muffle with 5 grains of borax glass. When the mass was thoroughly melted it was poured into a mold and the lead was again cupelled. The gold in the rock was all determined by concentrated assays in this manner, except when a series of assays were made from samples taken near together. In this latter case the average value in gold was determined by dissolving the whole number of the silver buttons.

Use of assays.—While various purposes may be subserved by assays of country rocks the main objects of those here described were first to ascertain in which of the rocks the precious metals could be detected, and second to trace the variations of tenor in different occurrences of the same rock. As a qualitative method exception can scarcely be taken to the dry assay, while even if the degree of accuracy reached in determining the absolute contents in precious metals of the Eureka rocks has been overestimated, the value of the results would scarcely be impaired; for it will hardly be denied that the results form a sufficient basis for a comparison of different samples of the same rock all containing very small quantities of silver and gold. For the purposes of this report it makes very little difference whether a certain mass of limestone really contains 10 cents or 20 cents, if it can be proved that a second body of limestone contains twice as much, or it may be half as much. In other words the main purpose was to ascertain the relative contents, not the absolute contents, of the samples assayed. Even if the methods employed were ideally exact it would be impossible to calculate the metallic contents of any large blocks of ground with precision, since it would be impossible to obtain samples which should correctly represent the average of the mass. The following pages contain all the assays of Eureka rocks, except those which were given in the chapter on the source of the ore, as well as some special determinations which were made of several minerals.

SAMPLES TAKEN EVERY EIGHT FEET IN THE SECOND CROSS-CUT ON THE FOURTH LEVEL OF THE EUREKA MINE, BEGINNING AT THE JUNCTION.

No.	Description.	Assay value in silver.[a]
		Cents.
1	Brownish crushed limestone	31
2	Yellowish crushed limestone	19
3	Bluish, slightly stained, hard limestone	24
4	Grayish limestone, much crushed[b]	....
5	Grayish limestone, harder	27
6	Grayish limestone	30
7	Grayish limestone, more broken	31
8	White limestone, not very hard	27
9	..... do	19
10	Crushed, broken, spotted limestone	22
11	Broken, grayish limestone	20
12	More broken, slightly spotted[b]	....
13	......do[b]	....
14	Same, but more compact	30
15	Bluish limestone, medium hard	28
16	......do	44
17	......do	15
18	Same, but softer	18
19	......do	22
20	......do	30
21	Medium hard, stained limestone	18
22	Crushed, stained limestone	20
23	Crushed, bluish limestone	19
24	Same, more compact	15
25	Crushed, broken limestone	18
26	......do	21
27	......do	25

[a] The average value in gold was 3 cents to the ton.
[b] Button lost in removing from cupel.

SAMPLES TAKEN EVERY FIVE FEET IN SINKING THE RICHMOND SHAFT FROM THE 1,100 TO THE 1,200-FOOT LEVEL.

		Cents.
1	Quartzite	23
2	......do	32
3	......do	25
4	......do	13
5	......do	14
6	......do	15
7	......do	10
8	......do	46
9	......do	10
10	......do	10
11	......do	16
12	......do[a]	....
13	......do	17
14	......do	....
15	......do	12
16	......do	15
17	......do	25
18	......do	8
19	......do	8
20	......do	15
21	......do	15

[a] Button lost in removing from cupel.

This quartzite contained iron pyrites and some molybdenite. All the silver buttons were dissolved together, and the resulting gold gave an average of 4 cents to each sample. The usual flux was employed in assaying this rock, except that 150 grains bitartrate of potash and 350 grains of borax were used.

Chlorination test of Richmond "red" and "yellow" ore.—The finely pulverized sample was leached for one week with hyposulphite of soda, and the difference between the assay value of the unleached samples and that of the leached sample showed that 36.1 per cent. of the silver contained in the ore was in the form of chloride.

ASSAYS OF VARIOUS ROCKS.

No.	Description.	Assay value.	
		Gold.	Silver.
			Cents.
1	Granite from Mineral Hill much decomposed	....	2
2	Red porous quartzite from Mineral Hill carrying much ferric oxide	Trace.	*a* 95
3	Weathered limestone from top of Ruby Hill, near U. S. Geological Survey monument	....	Trace.
4	Eureka quartzite from Caribou Hill, average of four samples	Trace.	10
5	Quartzite from near Membres shaft on Adams Hill	Trace.	*a* 69
6	Quartzite from end of cross-cut on third level of the Albion mine	....	Trace.
7	Rhyolite tufa from quarry back of Nob Hill, Eureka	....	
8	"Back" limestone from end of cross-cut on seventh level of the Richmond	Trace.	Trace.
9	Limestone from junction of first cross-cut and 1,050-foot level of the Richmond	....	5
10	Limestone from the contact with quartzite from first north cross-cut on the Richmond ninth level	....	4
11	Reddish "back" limestone from end of first southwest drift opposite second north cross-cut ninth level of the Richmond	....	4
12	White quartzite near contact with limestone, 1,050-foot level	Trace.	7
13	Decomposed rhyolite from "rhyolite winze," fifth level of the Phœnix	....	Trace.
14	"Front" limestone from same place	....	6
15	"Front" limestone from the second cross-cut on the sixth level of the K. K., 30 feet from main drift	....	6

a These two samples came from near low-grade ore.

SAMPLES TAKEN 30 FEET APART, BEGINNING AT THE END OF THE FIRST CROSS-CUT IN THE "FRONT" LIMESTONE ON THE SIXTH LEVEL OF THE K. K.

No.	Description.	Assay value in silver.
		Cents.
1	This limestone was of a grayish-white color, sometimes friable and sometimes compact. It did not differ from the ordinary limestone.	6
2		6
3		Trace.
4		10
5		4
6		Trace.
7		Trace.
8		5
9		9
10		Trace.
11	From contact with main fissure	11

Determination of carbon in various limestones.—The determinations were made in the following manner: One hundred grains of finely pulverized rock were dissolved in hot chlorhydric acid, filtered, and the residue was dried at above 100° and weighed. This insoluble part was ignited and the carbon determined by difference.

No.	Description.	Per cent. of carbon.
1	Black limestone at contact with quartzite on the cross-cut from shaft 1,200-foot level of the Richmond. Insoluble matter 6.5 per cent	1.50
2	"Back" limestone at end of cross-cut on the seventh level of the Richmond. Insoluble matter 7.24 per cent	0.84

A great deal of the limestone between the main and secondary fissures carries free carbon, the amount sometimes reaching 1 per cent.

An examination was made of the clay from the main fissure from all the points where it is exposed in the Eureka mine, for the purpose of determining the quantity of the carbonates of lime, etc., which it contained. The largest percentage of carbonates obtained was 85 per cent. and the lowest 15 per cent. As a rule the clay was most calcareous near the surface and the most silicious below, though there were local exceptions. As it was in part the product of attrition and decomposition of walls of quartzite, limestone, and shale, and no doubt in part also a product of the decomposition of rhyolite, its variable composition is accounted for.

Examination of quartz-porphyry from the Bullwhacker mine.—This porphyry occurs in the form of a dike in the above-mentioned mine. It contains numerous cubes of pyrite distributed throughout its mass, which sometimes measure as much as one-eighth of an inch. The pyrite is bright, and shows no signs of weathering except where it has been exposed for some time to the action of the air. Clean crystals of this pyrite were picked from the matrix and were assayed for gold and silver, 377.09 grains being pulverized and roasted sweet in the muffle. The roasted mass was mixed with 770 grains litharge, 580 grains bicarbonate of soda, 270 grains bitartrate of potash, and 700 grains borax. The whole mass was melted two and one-half hours and the resulting lead button cupelled.

	Per cent.
Value in silver, 65 cents	0.0017236
Value in gold, 80 cents	0.0001327

The amount of silver and gold contained in this porphyry when it was assayed without separating the pyrite was:

	Per cent.
Silver, 6 cents	0.0001591
Gold, 12 cents	0.0000199

From this it will be seen that the ratio of the gold to the silver was greater in the porphyry than it was in the pyrite itself, and that either the coarse crystals of pyrite (those that were selected for assay) were purer than the fine crystals, which is highly improbable, or that the porphyry carried gold and silver independently of the pyrite. Usually pyrite is found to be the matrix of gold and not of silver, but in this instance these relations seem to have been reversed.

A sample of porphyry from the surface, in which the pyrite had been completely decomposed by the continued action of the atmosphere, gave very nearly the same amounts of gold and silver as that which contained undecomposed pyrite. The results were:

	Per cent.
Silver, 7 cents	0.0001856
Gold, 13 cents	0.0000215

The amount of pyrite contained in the porphyry was 1.89 per cent. This was determined by Dr. Melville, assistant chemist of the Geological Survey, by calculation from the amount of sulphur in the rock.

That the iron pyrite did not carry all the gold and silver in this porphyry is shown by the fact that it contained when assayed separately only 80 cents (0.0001327 per cent.) gold and 65 cents (0.0017236 per cent.) silver, whereas it should have assayed $6.34 (0.0010518 per cent.) gold and $3.17 (0.0085062 per cent.) silver, there being 1.89 per cent. of it in the porphyry, had it contained all the precious metals present in that rock. There seems to be no doubt that the iron pyrite present in this porphyry is a secondary product; that is to say, that it was not crystallized out of the melted mass when it cooled, but that it was formed later either through the action of sulphureted hydrogen or sulphur in some other form upon the iron contained in the rock. It is difficult to conceive of the formation of pyrite from a melted mass under conditions which would permit of the iron retaining the extra atom of sulphur necessary to its composition. As it is evident that this porphyry contains silver and gold independent of that in the pyrite, it is highly probable that these metals were present in that rock before the formation of the pyrite, and that the same causes, probably those of solfataric action, which brought about the formation of the pyrite, effected a partial concentration of the silver and gold in this mineral.

This porphyry was also examined for lead. The ordinary methods of analysis failed to reveal its presence, although it was thought highly probable that it entered into combination with the rock in very minute quantities. I adopted the following method, founded on the well-known tendency of gold to retain small quantities of lead even when in a melted state and exposed to the air. Forty grammes of the finely-pulverized porphyry were mixed with 150 grammes of carbonate of potash in a porcelain dish, and the whole was moistened with an acid solution of terchloride of gold which contained 10 grammes of gold. The mass was dried and fused for four hours in a French clay crucible in a coke fire. The resulting gold button was then analyzed by Dr. Melville in the following manner: The gold was dissolved in aqua regia and filtered hot to remove traces of slag. The gold was precipitated with oxalic acid, the solution filtered, and the filter washed with hot water to remove chloride of lead. The filtrate was evaporated to dryness and ignited at the lowest practicable temperature to decompose the oxalate, and also to remove the excess of oxalic acid used in precipitating

gold. The residue was dissolved in nitric acid and filtered. The gold precipitated was treated with hot nitric acid to remove any oxalate of lead present; filtered, and this nitric acid solution was added to the first nitric acid solution obtained, and the whole evaporated to a small bulk, about 1 c. c. This was divided into two portions. One was tested with diluted sulphuric acid and the insoluble sulphate of lead was obtained; the second portion was tested with potassic chromate, when chromate of lead was precipitated and crystallized by boiling. The whole of the lead was then converted into sulphate and weighed. The weight was 0.0033 grammes. That there might be no question as to the character of the compound, the sulphate was finally reduced to metallic lead. The 0.0033 grammes (0.00825 per cent.) do not represent all the lead that was probably contained in the porphyry, as there was no doubt some loss, but the result is sufficiently accurate to establish the fact that this rock, although considerably metamorphosed, contained appreciable amounts of lead as well as gold and silver. As the assay value of the porphyry in silver was 6 cents (0.0001591 per cent.), there was about 52 times as much lead present as silver.

CHAPTER XII.

PROSPECTING.

Methods of prospecting in mines southeast of the compromise line.—The method of prospecting adopted by the superintendents of the mines on Ruby Hill has been somewhat different in the two regions which are separated by the compromise line. This line, which was adopted by the Richmond and Eureka companies as a boundary line between their respective claims, seems also to have been a natural division, as the ground on either side of it in the belt of mineral limestone exhibits somewhat different structural features. This difference has been fully explained in the chapter on the structure of Ruby Hill. The fact that most of the bodies of ore found during the earlier workings lay near the quartzite in the mines southeast of the compromise line, caused the adoption of a method of prospecting which consisted in sinking perpendicular shafts in the limestone, driving cross-cuts to the quartzite, which was called the foot wall, and running levels along the contact of that rock and the limestone. When this contact was not so irregular that the drifts became longer and more expensive than the advantages of a clay seam warranted, the levels were kept close along the quartzite, and cross drifts were run off into the limestone where indications were favorable for finding ore. Where the course of the quartzite face was too irregular the levels were driven near it parallel to its general direction. To define exactly what the Eureka miner considers to be "indications" is a difficult task. Fissures and seams, crushed, broken, and brecciated limestone, limestone stained with ferric oxide, and caves are considered to be good indications for ore—though drifts in which the country rock has shown all these phenomena have often developed nothing. On the other hand, no ore bodies have been found which, on one side or another, do not exhibit

some of these "indications." Ore bodies have sometimes been found after drifting hundreds of feet through the hardest and most unfavorable looking ground. This was the case on the seventh level of the Richmond (see Plate XIV.), where a drift had been run to make a connection. Where the ore was first found there was no indication whatever of its proximity until the ore body itself was encountered. The limestone was of a hard, compact nature and grayish color, and was not considered particularly favorable for ore. On the eighth and ninth levels some notice of the near approach to ore was given by stained limestone through which the drifts passed before it was reached, and by a fissure. Since the discovery these ore bodies on the different levels have been connected by upraises and winzes, and a well-defined ore channel has been established from the seventh to the ninth levels, even connecting with the west ore body above the sixth. True, the ore was not entirely continuous, but fissures, seams, and stained limestone extended over the whole distance, forming a connection between the ore bodies such that all of the latter would have been discovered if the indications had been followed downward from the large ore body on the fifth level.

Method of prospecting in the Richmond.—Owing to the nature of the Richmond ground it is doubtful if the method of following the quartzite and limestone contact adopted in the Eureka and other southeastern mines would have been productive of good results. The ore bodies in the Richmond, with one exception near the compromise line, do not touch the quartzite, but are invariably connected with some fissure. In the deeper workings of this mine it has been customary to drive straight levels in the limestone, independently of the quartzite, and to follow the fissures which may be encountered in all directions. Drifts are also run where other indications point to a possible ore body, or where it is necessary to cut up a large block of ground, which, though it may not be thought particularly favorable for ore, must not remain unprospected. This last method is made necessary in this mine by the fact that the ground which lies between the quartzite and the Ruby Hill fault is very extensive and ore bodies might easily exist in it without indicating their presence in any manner. Although ore has not been found near the quartzite in this mine, except in one instance, there is a possibility that it

may exist in that neighborhood in the upper levels, as there are no drifts for any distance along the quartzite except on the fourth and sixth levels. The company is now prosecuting a search in this direction with reasonable hopes of success. In fact there is a great deal of ground in all the upper levels of the Richmond mine which warrants systematic prospecting. In the mines southeast of it, however, the limestone has been very thoroughly prospected down to the point where the two fissures come together, and it is not likely that any very extensive ore bodies will ever be discovered in it, although it will probably be worked for a long time to come, for the sake of the small masses of ore that have been overlooked or neglected.

The structure of the country in these mines has been fully explained and the existence of a second limestone wedge, below the lower belt of shale, has been pointed out. The obvious method of prospecting this ground is to sink shafts through the lower belt of shale northeast of the present workings and to drift in the underlying limestone. Such a system of prospecting is at present being carried on in the Eureka, and if successful the example of this company no doubt will be followed by the others. A cross-section of the old and new workings of the Eureka is given in Plate VIII. As the two fissures in the Richmond mine are still very far apart, the same methods of prospecting which were followed in the upper levels are continued below.

Methods of prospecting on Prospect Mountain.—The methods of prospecting followed in the large mines of Prospect Mountain do not differ much from those in vogue on Ruby Hill. In the small mines the ore is usually followed from the surface down, either by vertical or inclined shafts, and the ore is extracted as the conditions of the ground permit. The Ruby-Dunderburg and Hamburg mines, as well as several others, are worked systematically with perpendicular shafts and levels run at stated intervals.

A portion of Prospect Mountain is being prospected by driving tunnels from both sides of the mountain at those points where the nature of the ground permits of obtaining a great depth with a comparatively small length of adit. As a means of opening mines tunnels are in general expensive and unsatisfactory. Usually the distance to be driven in order to attain any considerable depth is very great; the tunnel is nearly useless in explor-

ing the ground below its level, and is only advantageous as a means of ventilation and as an exit for the water. Ground below the tunnel level can be worked and drained to advantage only by the help of a vertical shaft from the surface, and such a shaft costs as much as if there was no tunnel. The advantages of the tunnel system in Prospect Mountain, however, as a means of prospecting are numerous. In the first place, owing to the topography of the country, it is possible in many places to gain a foot or more in depth with every two feet of tunnel. Again, the deposits are found throughout a belt of limestone over a mile in width, and are as likely to be discovered by a tunnel as a shaft. Moreover, many of the claims on the surface are owned by small companies, which cannot afford expensive hoisting machinery, but which could pay their proportion of the outlay necessary for the part of the tunnel developing their ground.

The presence of ore cannot be predicted with certainty, but this much at least can be said, that all the indications, and the results so far obtained, point to the existence of numerous ore bodies in the heart of Prospect Mountain, and although mining for the precious metals has not been reduced to anything like as great a certainty as is the case with coal and iron mining, a skillful use of the knowledge already obtainable will in some measure reduce risks which invariably attend mining operations. The air and ventilation are good in all the mines of the district where proper connections have been made, even in the lower levels.

Electrical observation and assays.—In describing the second list of assays, page 84, reference was made to some observations by Dr. Barus in the Richmond mine in regard to the electrical activity of ore bodies. Mr. Becker, in summarizing this investigation,[a] says: "Of the different surveys made, the one on the 600-foot level of the Richmond mine, west drift, presents the greatest interest, because it was here that all the precautions necessary could be satisfactorily applied. The line of survey, moreover, lay completely outside of the ore body, and all the points tapped were in rock, essentially of the same kind. The measurements were made in various galvanometric ways, and the results were subsequently checked by a 'zero'

---

[a]The methods employed and the results obtained are fully explained by Dr. Carl Barus in the Geology of the Comstock Lode, Chap. X.

method. It was found that the distribution of potential along the length of the drift, even after an interval of four months, has not materially changed, and that on passing from barren rock toward and across the ore body, small, though decided, variations of potential were encountered in its vicinity.

"*Results.*—The electrical effects observed were too distinctly pronounced to be referable to an aggregate of incidental errors, and they were of the character which must have been produced had the ore bodies been the seat of an electromotive force. The experiments made cannot be said to have settled the question as to whether lode currents will or will not be of practical assistance to the prospector. Indeed, as yet it cannot even be asserted with full assurance that the currents obtained are due to the ore bodies. What has been observed is simply a local electrical effect sufficiently coincident with the ore body to afford in itself fair grounds for the assumption that these contained the cause. Giving the investigations of Fox and Reich proper weight, however, the supposition that the currents in the Richmond mine were not due to the ore bodies is exceedingly improbable. But unfortunately they are so weak as to require an almost impracticable delicacy in the researches designed to detect and estimate them. It is highly probable that under certain circumstances more powerful currents are generated than those found in Eureka. It is not unlikely, for example, that galena, cinnabar, and the copper sulphosalts produce electrical effects of far greater magnitude, and that the method might be readily available for the discovery of such ores. The results thus give much encouragement to further investigations in this direction."

Fig. 5, page 144, represents the plotted curve resulting from Dr. Barus's determination of potentials, and Fig. 6, same page, represents the curve resulting from the plotting of the assay values of the samples taken from the points I., II., up to XVIII. In plotting the electric as well as the assay curve, the linear distances between the points I. and II., I. and III., etc., are taken as the abscissas, the values of the potentials being the ordinates in the electric curve, and the assay values being the ordinates in the assay curve. Beyond the point XVIII. no samples were taken, as it was not possible to find Dr. Barus's points. The assays were made some

time after Dr. Barus's electrical experiments, but before his results were known to me. Fig. 2, page 82, represents the position of the points I., II., III., etc., as well as the relations of the ore bodies to the formations. Mr. Becker, in his summary, states that the question of the practical value of lode currents to the prospector has not yet been settled.

The same may be said to be true of the value of the assays of country rock as a means of determining the positions of ore bodies. Nevertheless the coincidence of the two curves just mentioned, although by no means complete, is yet too remarkable to be overlooked. The assays taken at points

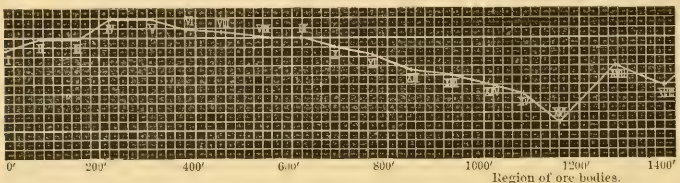


Fig. 5.—Electric curve.

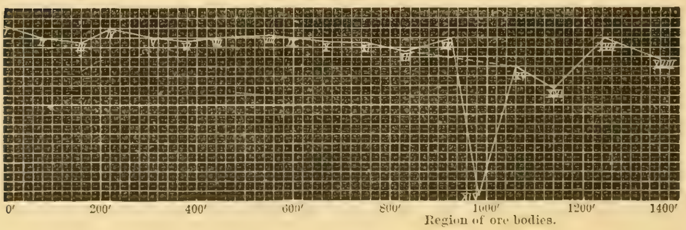


Fig. 6.—Assay curve.

XIII. and XIV. are abnormal. Although other assays were taken afterwards at these two points, no assays as low as XIII. nor anything as high as XIV. were obtained. If, therefore, the assays XIII. and XIV. were left out, and the points XII. and XV. joined by a straight line, a curve almost identical with that of Dr. Barus would result.

Practical use of assaying in prospecting for ore.—There are many things that render it a very difficult matter to make practical use of the assay value of the country rock in prospecting for ore bodies. The maximum differences between the various specimens are in any case small; ordinarily the country

rock is not of a sufficiently homogeneous character to exhibit a uniform increase in value as an ore body is approached. Usually when there is a marked increase in this value there are other indications of the presence of ore bodies, such as stained and broken rock, fissures, and like phenomena, which lead the miner in the proper direction; and the determination of the direction in which an ore body lies from a point in a drift where good assays have been obtained is a very difficult matter, while prospecting in a wrong direction is always a very expensive affair. At a remote point, where data indicating the direction of an ore body would be of exceeding utility, the relative differences in the assays are so small that no marked advantage can be obtained from them and they would be very liable to mislead the prospector. Notwithstanding these drawbacks, it is possible to render the assaying of country rock of practical advantage, especially when the diamond drill is used as a means of prospecting. Subsequent to the electrical experiments and to the determination of the values of the country rock on the 600-foot level of the Richmond, a considerable body of ore was discovered just a few feet below this level near the point XV., where the electrical phenomena and the assays indicated the presence of ore. The discovery was made, however, by following a stratum of ferric oxide in a cross-drift a short distance from the main level, and was not due either to Dr. Barus's experiments or the assays of country rock, as before the discovery of this ore body it was supposed that the phenomena observed were referable to the large body of ore which existed above this level. This body of ore, however, was further removed from point XV. than the ore subsequently discovered.

The correspondence between the assay values of the rock and the values of electrical potentials found by Dr. Barus is clearly not accidental. If it is possible that the phenomena are connected as cause and effect, or that the differences of potential are due to the traces of ore in the rock, then both methods only lead to the detection of local differences in composition, which may indeed be referred with some probability to the presence of ore bodies in the neighborhood, but which might also be due to an accidental dissemination of metallic compounds and be independent of the existence of ore in considerable quantities. On the other hand, if the two

series of phenomena are to be regarded as two effects of one cause, and are not immediately dependent upon one another, each affords a remarkable confirmation of the inferences which would be most naturally drawn from the other. The facts were submitted to Dr. Barus for his opinion, which is as follows:

"It is entirely impossible that there should be any direct connection between the assay value of the rock at a given point and the value of earth potential for the same point. The nature of the distribution of electrical potential can be made clear to those unfamiliar with the subject by the aid of an analogy. Instead of drawing inferences with reference to an ore body considered as a source of electrical activity, I will suppose that we have to do with a hot body, that is, one whose temperature is decidedly above that of the surround-

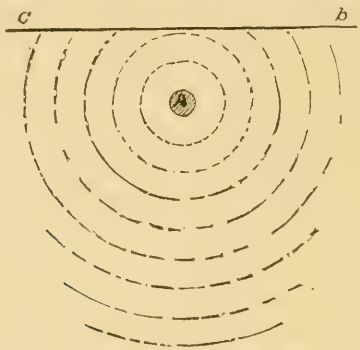


FIG. 7.—Illustration of electrical activity.

ing rock. Let c b, Fig. 7, represent the surface of the earth. Let A be an area (in section) of constant high temperature beneath it. Suppose the body has been in place for an indefinite length of time, so that the thermal distribution has become stationary. Let the problem be that of finding the body A from observations made on the surface of the earth. The first step would be to take earth temperatures at convenient number of points intermediate between c and some remote point, b. If the distances were then plotted as abscissas and the earth temperatures as ordinates, a curve would be obtained which in the simplest case would be characterized for an abscissa corresponding to a point nearest the hot body A by a maximum.

"By an extension of the same reasoning, it is clear that if the surface were level and horizontal, and if a complete thermal survey of the surface were to be made, the result might be expressed by a series of isothermal contours analogous to those by which topographical features are ordinarily presented, and that the summit of an elevation on the thermal map would lie vertically above the hot body.

"Similar methods of procedure and expression are applicable to a center of electrical excitation. If the body were electrically active, an electrical survey would result in the determination of a series of equi-potential contours separated by a fixed difference of potential, and these would culminate above the ore body. In short, replace temperature by potential, isothermal by equi-potential, and the consideration made in reference to the hot body will apply to an ore body, only that in the case of electrical excitation we have to do with circumstances vastly more complex, with a body, as it were, in part hot, in part cold, or one over which heat is irregularly distributed.

"The remarks made on the surface manifestations of a subterranean hot body apply readily to any imaginary line or any imaginary plane lying beneath the surface and sufficiently near the hot body. To make the case perfectly general, however, we should have to consider the isothermal surfaces themselves in their actual position and contour. The first of these would completely envelop the hot body; whereas, subsequent ones intersect the surface of the earth until finally they would become indistinguishable from the normal terrestrial isothermal, as shown by the dotted lines in the figure. Similarly, in the case of a detailed electrical investigation, it would be necessary to trace the equi-potentials as surfaces surrounding and intersecting the electrically active ore body. The presence of an ore body is evidently manifested throughout the whole superficial and subterranean region in which the equi-potential surfaces are traceable or in which an electrical disturbance due to the presence of an ore body exists, and the applicability of the electrical method of prospecting consists in the fact that the indications of the existence of an ore body occupy a space greatly in excess of the size of the body itself, namely, the whole region of sensible electrical excitation.

"The analogy between the electrical method and the method of assays is clear, for in the latter advantage is also taken of the fact that the indications of ore occupy a greater space than the ore body itself. The differences are also clear, for while the assay method depends upon the solubility of the ore, the permeability of the rock, the distribution of fissures, and the like, the electrical method depends upon the distribution of electrical activity in the body producing the effect, and upon the electrical conductivity of the surrounding rock. The two methods are, therefore, entirely independent, and it is a particularly interesting fact that the results obtained in the Richmond mine were accordant. Mr. Curtis and I have met with a coincidence of two independent effects of the same cause, both of which indicate in different ways the presence of ore in the vicinity of point XV. of the 600-foot level of the Richmond mine. It is gratifying to find that an ore body was actually discovered, subsequently to our experiments and independently of them, precisely where we had most reason to look for it. I greatly regret not to have been able to be present to study the distribution of potential relative to the new body in detail.

"There is one more remark with a bearing on these inferences which I desire to make. The relation of the earth-potential encountered along any line of electrical survey to distance, when expressed graphically, appears as a broken line possessing certain distinct characteristics. I proved, however, that the progress in the values of earth-potential, observed on passing from one point of a drift to another, is continuous, and that therefore the potential line in our diagram, however sinuous, never suffers a break of continuity; whence it follows that we may regard the curves obtained as containing unknown disturbing effects superimposed on the decidedly larger electrical effect attributable to the ore bodies. I infer that in any extended line of electrical survey, besides the large field of electrical excitation due to the ore bodies, very many smaller fields, distributed throughout the mine, are constantly encountered and intersected."

Use of the method of prospecting by assays.—The method of prospecting by assays has one important advantage over the electrical method; it can be carried out with comparatively little expense and with little loss of time. It must be remembered, however, that the assays will be useless unless made with

the greatest care. And as many assays as convenient should be made in order that local differences in the rock should be rendered as small as possible. In running a drift, it would be well to take four assays per day, which might be used separately or averaged. Care should be taken to exclude all seams containing traces of ore, which can be assayed separately if desired, as it is the enriching of the country rock itself that it is necessary to observe.[a]

Great caution should be employed in making use of these assays and the results should be carefully compared with other indications in the country rock and the general structure of the ground. With proper precautions the assaying of the country rock will in many instances become an important aid to the miner. The method is better adapted to the discovery of large and irregular bodies of ore in a formation similar to that in Eureka than it is to the search for small, though rich veins.

---

[a] The methods used in assaying the Eureka ores are fully explained in Chapter XI.

CHAPTER XIII.

TRIBUTE SYSTEM.

Wages.—The wages paid to miners in Eureka District, as well as in most mining camps of Nevada, are $4[a] per shift of ten hours. In most of the mines on Ruby Hill the shafts are sunk and levels opened by contract, as are likewise drifts, cross-cuts, winzes, and upraises when driven in the country rock. The companies furnish timber, lumber, and tools, and the contractors candles, powder, fuse, etc. The waste is usually removed by men paid by the company. The contract price varies with the kind and size of the excavation and the hardness of the rock. For drifts run by the Burleigh drill, the minimum price paid the miner is $5 per running foot, and the maximum $12. The latter price is only paid in extraordinarily compact and "short-breaking" ground; $9 per foot would be about the average for hard ground. The cost per foot for blasting material is from $1.25 to $1.80. For drifts run by hand-drills the cost is from $6 to $14, but the cost of blasting material is only about one-fifth of what it is when Burleigh drills are used. In sinking shafts and winzes the cost is somewhat greater. Where blasting is not necessary drifts are run for less than $3 per foot. At these rates it is supposed that the miner will earn something over $4 per shift, as contractors usually work harder than miners paid by the day. As a matter of fact, however, contractors often make less than $4, as work by the shift at those wages is usually scarce, and they prefer earning less to remaining idle, while the rules of the Miners' Union prohibit them from taking smaller wages.

Ore is generally extracted from the chambers by miners on day's pay, except where it is removed under "tribute"—a *pro rata* method of paying

---

[a] In some places where the work is particularly hard or dangerous, as is the case in some mines on the Comstock, the length of shift is reduced to eight hours, and even less.

miners which has been in use for many years in Cornwall and elsewhere. A general description of this system as it has been applied in the mines of Eureka District will perhaps be of interest.

The tribute system.—In the year 1878, in the older workings of the Eureka mine, there was a very considerable amount of ore which had not been extracted from the ore chambers, either through oversight or improper mining. Many small ore bodies also had been passed over as too poor or insignificant to be worth removing, and there was reason to believe that undiscovered ore bodies of small size existed, as turned out to be the case.

In the year mentioned, Mr. T. J. Read, superintendent of the mine, introduced the method of taking out ore on tribute, in order to utilize the large quantities of it known to exist in the earlier workings. The ground which was to be worked in this manner was divided up into blocks or "pitches," as they are called by the Cornish miner. These pitches were allotted to individuals or companies (which usually consisted of two men), and 10 per cent. of the assay value in gold and silver of all ore above $40 was paid to tributers. This rate was paid for about one year when it was increased to 15 per cent. Then a new schedule of prices was arranged, based upon the assay value of the ore: $6 per ton of 2,000 pounds was paid for $40 ore and $30 for $100 ore, with proportional prices for the intervening grades. Finally, in 1881, still another schedule of prices was adopted: $2.50 was paid for ore assaying $30 per ton, and 50 per cent. of all that it assayed above $30. Thus $65 ore brought the tributer $2.50 plus $17.50, or $20. The company furnishes tools, hoists the ore, and transports it to the smelting works. The tributer supplies his own candles, fuse, powder, etc., as well as timber, buying them from the company at or near cost, handles his own waste, and delivers his ore at the shaft. When a tributer runs a prospecting drift and does not succeed in finding ore, it is not customary to charge him with powder, etc. In those cases where a tributer strikes a very large body of ore requiring timbering in square sets, the ground is taken away from him after he has been allowed to make remunerative wages. Such a fortunate strike both for the tributer and the company has only occurred in one instance since the tribute system was introduced.

Extracting ore under the tribute system has also been introduced in the Richmond as well as in many other mines of the district, and it has been found to work very well.

Advantages and disadvantages of the tribute system.—The tributers sometimes fill up drifts and other workings which ought to be kept open, and injure the mine generally, but this is the case only when they are not properly restricted and the foreman of the mine does not attend to his duty. Ground worked under the tribute system soon acquires an ill-kept, disorderly appearance not calculated to impress visitors favorably. The approbation which orderly galleries excites in the mind of a mining man is not founded on love of neatness, however, but on the fact that it facilitates the operation of the mine. It must be remembered that the ground is not given over to tributers until it has been practically abandoned by the company, and that the ore which is obtained in this manner is nearly clear gain; and since the ground left by the tributers is entirely valueless, there is no object in maintaining it in working order. In fact, extraction under the tribute system is analogous to cutting away the pillars of a coal seam rather than to more regular mining operations.

Although some tributers are fortunate and discover valuable deposits of ore, by far the greater number do not make miners' wages; but men generally, and miners in particular, prefer to run the risk of making nothing if at the same time they have the chance of getting extraordinary remuneration for their labor. The difficulty of obtaining continuous employment at day's pay also acts as an inducement to tributers. As the large ore bodies are worked out, the demand for such labor decreases and many miners are thrown out of employment who prefer to work on tribute to seeking their fortunes in new camps. As adopted in Eureka District the tribute system has been very successful.

CHAPTER XIV.

TIMBERING IN THE EUREKA MINES.

The method of timbering.—The methods employed in timbering shafts and drifts in the mines of the Eureka District do not differ in any material respect from those employed in other regions of the Pacific slope, while the system adopted for preventing the caving of excavated ore chambers originated on the Comstock, and has been described by Mr J. D. Hague.[a] It is now in use in all districts of the West where the size of the ore bodies has made it necessary to depart from the methods usually employed in small lodes. The framing of the timbers at Eureka, however, presents some particularities to which it is desirable to call attention.

Physical nature of the different formations.—As a rule, the limestone composing the ore-bearing zone requires but little timbering where it is penetrated by drifts and winzes, and it is only where it has been crushed to a powder that workings of this character need to be kept open by timbers. Where drifts have been run along the line of the quartzite and limestone contact, timbering is almost always necessary, as the quartzite and accompanying clay scale off and in the course of time fill up the drift. Drifts in the quartzite itself stand better, but, nevertheless, often require timbers, especially where there is much water. There are but few workings in the shale, but if there were, much timbering would no doubt be required to keep the ground open for any considerable length of time, as is shown by the cross-cut through the lower belt of shale on the 1,200-foot level of the Locan shaft. The "crawling" of the shale in this instance is much increased by the water present in it at this level, and it has been necessary to retimber the cross-cut several times within a few months. Shafts and winzes in the limestone

[a] Exploration of the Fortieth Parallel. Vol. III.

of course require some timbers, but usually no more than are necessary for the support of ladder-ways, etc. The Richmond shaft, over 1,200 feet deep, which passes through shale, limestone, and quartzite, is only "cribbed" for the entire distance with two-inch plank, except at the stations, where timbers are used. Timbering, however, will eventually be necessary in this shaft, not only below the water level but above as well. Below the water level the limestone stands very well, owing partly to its nature and partly to the more compact character of the rock as depth is attained. The quartzite ought always to be timbered below the water level, and it would be found more economical in the long run to timber all working shafts carefully.

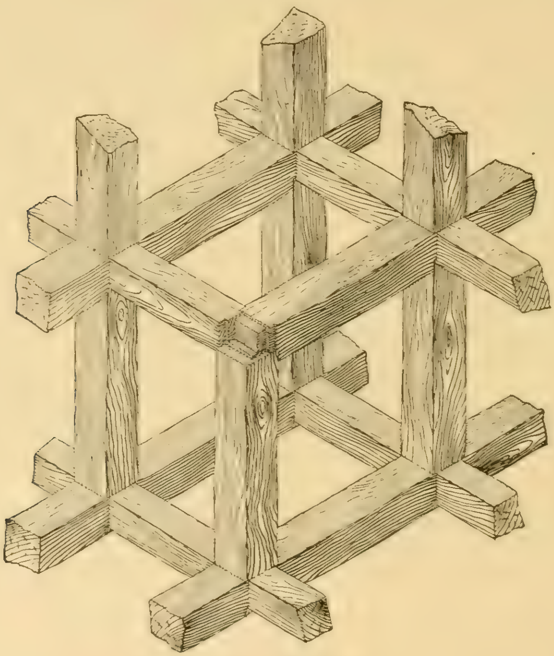


FIG. 8.—Set of timbers.

Method of timbering.—Fig. 8 represents a complete set of rectangular timbers, as they are used in carrying up a stope in an ore body. These tim-

bers are similar in their general features to those in use on the Comstock. It is only as regards the manner in which they are framed that they differ, and even in this respect the differences are but slight.

When an ore body is encountered in driving a drift, it is usual to place the first sill across the drift, laying the ties parallel to the drift. This is done to retain as wide a space as possible for the passage of the car, the sills being longer than the ties. In carrying up the timbering the timber which forms the cap of a lower set becomes the sill of the set above it. The same is the case with the ties. In beginning a stope the sills often consist of a long piece of timber in which the posts are mortised at their usual distance apart. As each set is raised the caps are covered with two-inch plank, and in this way floors are constructed. The spaces between the floors and timbers are filled with waste, and thus a compact mass is formed from one side of the ore chamber to the other and from the bottom to the top, which takes the place of the ore removed, and which is capable of sustaining the enormous pressure exerted by the surrounding rock. The timbers are wedged and braced against the limestone walls of the cham-

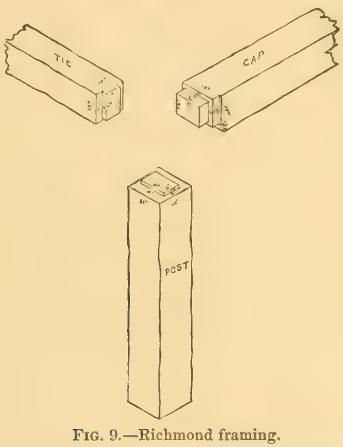


FIG. 9.—Richmond framing.

bers, so that the whole stands solid. It is customary to fill in with waste, as opportunity offers, the absence of that peculiar "crawling" ground so common on the Comstock obviating the necessity for immediate filling.

Sometimes the flooring is removed before the spaces between the timbers are filled.

Method of framing in the Richmond.—Fig. 9 represents the posts, caps, and ties as framed in the Richmond mine. The tenon of the post is 9 by 6 by 1⅛ inches; that of the tie, 9½ by 6 by 1⅛ inches. The tenon proper of the cap is 9 by 7¼ by 3 inches, but there are several shoulders on the cap made to fit the spaces left between the post and tie. The dimensions of all these different parts can be seen in Fig. 9, and the manner in which they come together in Fig. 8.

This method of framing is complicated, and therefore expensive, but it is claimed that it gives great strength to the joint. Upon an examination of Fig. 9 it will be observed that the tenons of the posts, and also some of the shoulders of the caps, are cut somewhat short of what would be their proper length if they were framed to meet exactly. This is to allow the timbers to come together easily, as any irregularities in the joints caused either by imperfect cutting or subsequent warping would interfere with their proper fitting were not some space allowed. This is the more necessary on account of the complicated system of joining. Pressure soon causes any imperfect parts to meet.

Method of framing in the Eureka.—Fig. 10 represents the timbers as they are framed at the Eureka mine. The tenon of the post is 8 by 8 by 2 inches, that of the cap 6 by 8 by 4 inches, and that of the tie 12 by 8 by 2 inches. The tenons of all these are also cut somewhat scant, but as there are not so many shoulders as in the Richmond timbers they do not need as much play and are easily fitted together. Timber men usually prefer the Eureka to the Richmond method, contending that the timbers are equally strong and more easily framed. The Eureka timbers seem best calculated to resist pressure from all sides, while those of the Richmond offer the greatest resistance parallel with the caps. This would be what was required in timbering an ore body the greatest dimension of which was along the course of the lode, as is the case with Comstock bonanzas. In this case the ties would be placed parallel to the walls and the caps at right angles. In Eureka, however, the ore bodies are very irregular and the pressure is usually about the same from all sides. On the first discovery of an ore chamber, too, it

is impossible to determine with any certainty what may be its ultimate course, and consequently how the timbers should be placed. It is, therefore, well to have a system of timbering which will be equally effective in

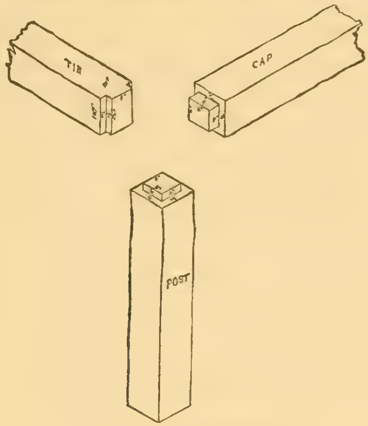


FIG. 10.—Eureka framing.

all directions. When all the pressure comes from above, which, however, is rarely the case, it would be well to have the ends of the posts rest directly on each other, not allowing the tenon of the caps to intervene.

Material and size of the timbers.—The usual length of the posts is 6 feet between shoulders; that of the caps and ties 5 and 4 feet, respectively. The timber used is pine from the Sierra Nevada. It is hewn 12 by 12, 10 by 12, or 10 by 10 inches square, and is of excellent material. The ties used in the Richmond are 10 by 10 or 10 by 12 inches, as the case may require. In the Eureka they are usually 12 by 12, though occasionally they are but 10 by 12 inches. Sets of timbers 10 by 10 inches are sometimes used when the ground will permit of it and the ore bodies are small, but 12 by 12 inches for the posts and caps at least is the rule.

The timbers are cut into the required lengths by circular saws, and framed by hand. Split lagging and sometimes poles are used in the drifts and small ore bodies where the heaviest timber and planking are not required.

CHAPTER XV.

METALLURGY OF THE EUREKA ORES.

Reduction of ores.—Almost all the ores of Eureka District are reduced either at the Richmond or Eureka smelting works, which are situated, respectively, at the south and north ends of the town of Eureka. At different periods other companies have smelted their own and custom ores, but it has usually been found most advantageous to have ores reduced at one or the other of the above-mentioned works, as the large scale on which their operations are conducted enables them to smelt at a less cost.

No exhaustive investigation of the metallurgical processes carried on in Eureka is intended in this report, and only such a general description will be given as will enable the reader to compare the general methods and apparatus with those employed in other districts. The ores have already been described in a separate chapter, and an analysis of those of the Richmond mine, which closely resemble all others in Ruby Hill, has been added, so that a further description of them will be unnecessary here.

Description of Richmond works.—The works of the Richmond company, which are the largest and in some respects the most complete, are situated in the southern part of the town of Eureka, and are connected with the company's mine on Ruby Hill by a narrow-gauge railroad, about three miles in length. The distance to the mine by wagon road is somewhat shorter, as, on account of the difference in elevation between the town and the hill, the railroad could not be built in a straight line. These works have a capacity of from 250 to 300 tons per day, according to the nature of the ore to be reduced. A refinery is connected with these smelting works, in which the furnace lead is calcined and the silver and gold are separated from it.

Description of furnaces.—In the smelting department there are four shaft furnaces with an individual capacity of from 50 to 100 tons of raw ore per day.

These furnaces, although they differ slightly in size, are all constructed in nearly the same manner. The portion of the stack above the smelting zone is constructed of ordinary brick and is cylindrical in form. It is supported by cast-iron pillars, which rest on a solid foundation. The smelting zone itself is composed of a water jacket, or rather several water jackets, called "baches," and is oblong in shape. The "baches" are hollow boxes of boiler plate 30 inches high, 20 inches broad, and 6 inches deep at the top and 4 inches at the bottom. In the center of each is an opening for a tuyere, which may be a water tuyere or merely a pipe to convey the blast. The water tuyeres are long, and are used at those points where it is necessary to convey the blast for some distance into the charge. The baches are inclined a little outward at the top on the upper edge of the crucible or lead well. They are joined to the stack above by a course or two of fire-brick luted with clay. They are fastened to each other on the sides by key-bolts, which can be easily removed in case of an accident, such as the burning through of the iron of the bache. This arrangement allows the removal of one of these water jackets and of its replacement by a new one without interference with the working of the furnace. The baches are open at the top and continually receive a stream of cold water which keeps them cool. The iron comes in direct contact with the charge as in all water-jacket furnaces. The furnace has an open hearth at one end with a slag spout as well as one for speiss. The latter is placed one and one-half inches below the former. The lead is allowed to run out of an opening on the side of the lead well, which is a very short distance below the speiss spout. When one of the large furnaces is working properly there is a continuous flow of all the three smelting products, slag, speiss, and lead, from the crucible. The furnaces are barred out regularly once every twelve hours, the front bache being removed for that purpose. It is said to have been proved by repeated experiments that the nature of the Eureka ores renders their advantageous smelting in a furnace with a closed hearth impossible, as the large quantity of iron in the ore makes a continual barring out necessary in order to prevent the formation of "sows." The separation of the different smelting products, slag, speiss, and lead, is tolerably complete.

Composition of charge and analyses of slag and speiss.—The analysis of the Richmond ore shows less than 3 per cent. of silica and about 30 per cent. of iron sesquioxide. In order to make a slag with sufficient silica for good smelting, quartzose ores are added, or quartzite when such ores are not to be obtained. The slag and speiss, analyses of which by Mr. F. Claudet are annexed, resulted from smelting the ore, an analysis of which by the same chemist is given on page 60. The material furnished Mr. Claudet is stated to have been the regular daily samples taken throughout an entire year.

SPEISS.

	Per cent.
Arsenic	32.95
Antimony	.13
Molybdenum	2.81
Sulphur	3.34
Lead	2.18
Copper	1.06
Iron	57.02
Zinc	.07
Lime	.34
Silica	.23
Silver and gold	.029

Silver, per ton of 2,000 pounds, 8.01 ozs.; gold, 0.43 oz.

SLAG.

	Per cent.
Silica	23.67
Iron protoxide	58.32
Alumina	1.64
Lead oxide	3.51
Metallic lead	3.26
Bismuth	
Copper oxide	1.08
Zinc oxide	4.44
Manganese oxide	.23
Molybdenum	.32
Arsenic	.25
Antimony	
Sulphur	2.19
Lime	4.78
Magnesia	1.27

Silver, 0.58 oz. to the ton of 2,000 pounds; gold, trace.

This speiss contains an unusually small atomic proportion of arsenic, for if the sulphur is supposed to be combined with the metals and arsenic an arsenide of iron corresponding to the formula Fe_5As_2 remains, whereas in many speisses the arsenide of iron is either Fe_3As_2 or Fe_4As_2.

The analysis of slag shows that it is very basic and the formula deduced from it is that of a subsilicate Although this slag is very much more basic than is ordinarily the case where lead ores are profitably smelted, yet the Eureka smelters claim that they obtain better results than they would if the percentage of silica was much increased. The amount of arsenic in the ore, which causes the formation of speiss, without doubt renders the smelting of such a basic mixture possible. The flue dust, which is collected in long canals connected with a high stack on the hillside, is mixed to a thick paste with clay and water in the proportion of one part clay and two parts of dust, is somewhat dried, and added to the charge.

Example of a charge.—The following is an example of a charge of one of the furnaces:

Charcoal	scoops	40
Richmond ore	shovels	50
Ruby-Dunderburg (silicious ore)	do	10
Hoosac slag (silicious and rich)	do	50
Silver Lick (silicious ore)	do	6
Adobe flue dust	do	4
Speiss	do	1
Quartz ore	do	2

The Richmond ore contained three to four per cent. silica. The rest of the silica required for smelting is supplied by the Ruby-Dunderburg, Silver Lick, and other more or less quartzose ores, and by the Hoosac slag. The Hoosac slag was a rich slag from the imperfect smelting of lead ore with a quartz gangue. The charge is supposed to contain about the following percentages:

	Per cent.
Ferric oxide	40
Silica	20
Plumbic oxide	22
Other minerals	18
	100

Fuel.—The fuel used in smelting is charcoal made from the piñon pine. The coal produced from this wood is usually very good, and in this district it is of an exceptionally fine quality, the method by which it is manufactured having been brought nearly to perfection. Nearly all the coal-burners are Italians who have been attracted to this country by the opportunities offered for this particular class of labor. About 30 bushels of coal are required per ton of ore smelted, and the present cost is 30 cents per bushel.

Refining.—The lead from the smelting of Richmond ore does not usually require calcining. Hard lead is refined in large rectangular cast-iron pans, which will hold about 14 tons. The time required for softening is from two to four days, according to the quality of the lead.

Pattinsonizing.—The process used in concentrating the silver in the lead is the Luce & Rozan process, a modification of the Pattinson method, and is carried on as follows: The principal portions of the apparatus employed are two melting pots, one comparatively large crystallizing pot on a lower level, two receivers or molds below the crystallizing pot, and a crane to handle the cakes of lead after they have solidified in the molds. The upper pots are provided with covers and the lower one with a hood and pipe to carry off the steam and fumes. There is a pipe by which water is let into the crystallizer above, and one for admitting steam into it below. The steam valve consists of a horizontal pipe which penetrates to the center of the pot, and within this pipe there is a rod with a button on the end which enters the pot. On screwing the rod in, the button is removed from the end of the pipe and steam is forced into the melted lead through which it is distributed, by means of a perforated false bottom, throughout the whole mass. The receiver or molds on each side of the crystallizer hold 7,400 pounds of lead. When the lead is drawn off into these molds an "eye" is introduced into the melted mass before it cools. In removing these cakes the hook of the crane chain is inserted in the eye, and by means of the steam hoist attached to the crane they are removed from the molds. When either market or rich lead is drawn from the crystallizer, molds on two wheels and a peg are placed in a semi-circle around the discharge pipe and filled by a movable spout. The cakes are hoisted and placed in the melting pots by the crane. It is unnecessary to enter into a

further description of the mechanical details of the apparatus and process, which have been repeatedly described in the technical journals.

The first operation consists in melting down 50 tons of lead in one of the pots. This is then drawn off into the crystallizer, and water is turned on to chill the lead, because much time would be required to cool it by radiation. Then steam is admitted, which thoroughly stirs and at the same time completely refines the melted mass. When the crystallization is completed, which takes place in about one hour from the time the lead is drawn off from the melting pot, about two-thirds of the mass is in the form of crystals assaying 100 ounces to the ton and one-third is still melted, containing about 460 ounces. This rich lead is drawn off into molds and taken to the cupel furnaces. In the mean time enough lead of the value of 100 ounces to the ton has been melted in the second pot, and is allowed to flow into the crystallizer, where it immediately dissolves the crystals of 100-ounce lead. This is now crystallized, giving 75-ounce poor lead and 150-ounce rich lead, which is drawn off as before. The lead is thus crystallized until market lead of about the value of one ounce to the ton is obtained. This requires nine crystallizations, which give lead of approximately the subjoined values:

LEAD FROM THE CRYSTALLIZATION OF 220 OUNCES LEAD.

	Ounces to the ton.
First crystallization	100
Second crystallization	75
Third crystallization	50
Fourth crystallization	30
Fifth crystallization	18
Sixth crystallization	9
Seventh crystallization	5
Eighth crystallization	2.5
Ninth crystallization	1.25

It is found that there is no sensible enrichment of the lead after it has reached 550 ounces (less than 2 per cent.). The ratio of the gold to the silver in the lead from the smelting furnaces is about 1 to 32 by weight, or in value about $1 gold to $2 silver.

The use of steam in this process appears highly advantageous. The stirring produced is probably more thorough than that accomplished by

machinery, which as hitherto designed is somewhat complex and subject to frequent stoppages for repairs. The steam is also in part decomposed at the temperature maintained, and thus accomplishes a very considerable refinement of the lead during the process of concentration, producing an excellent market lead from comparatively hard bullion.

Cupellation.—The rich lead is cupelled in furnaces of the English model with bone-ash tests. The test holds from a ton upwards. It is filled with lead which is brought to a cupelling heat and an air-blast is turned on. This blast is preferred to steam, as the latter becomes moist and also increases the loss in silver, although the loss in any case is slight. The test is kept full of lead by adding bars one by one at the back of the furnace and allowing them to gradually melt down. It is tapped every twenty-four hours, when from six to eight bars containing two-thirds silver are obtained. Sixty such bars, on a second cupellation, give in about sixteen hours 16,000 ounces of doré silver, .965 fine in silver and .030 fine in gold. A test lasts about ten days. In refining, concentrating, and cupelling mountain mahogany wood is used. It is a very superior fuel, and costs from $10 to $12 per cord.

The poor litharge, containing about an ounce to the ton, is reduced to market lead in reverberatory furnaces, with refuse charcoal from the bins. The rich litharge, containing as high as 75 ounces, is resmelted with a furnace charge, as there is almost always a dearth of lead in the ores.

Advantages and disadvantages of refining.—It is a question whether Eureka is an advantageous locality for refining bullion, fuel being high and labor $4 per day. Refining on the spot obviates the necessity of paying interest upon the money required to freight the unparted lead to a refinery in San Francisco or the East, and the market is frequently so overstocked with lead that it is better to wait for a rise before shipping. On the other hand, high charges are incurred in expressing the doré silver, which would be avoided if the bullion were transported by freight as it comes from the furnaces.

CHAPTER XVI.

ADAMS HILL.

Topography and formations.—The summit of Adams Hill is situated about 3,400 feet nearly due north from the top of Ruby Hill. The hill is a gentle elevation which rises to a height of 6,940 feet above sea-level and slopes with a gradual descent toward the valleys on the west and north. It is divided from Ruby Hill by a moderately deep ravine which enters Spring Valley.

The principal part of the hill is composed of Hamburg limestone, the Secret Cañon shale forming a band running east and west along its southern flank, and the Hamburg shale making its appearance in a like manner on the northern slope. To the north of the Hamburg shale and to the east of the Hamburg limestone the Pogonip limestone is exposed. The nonappearance of the Hamburg shale between the Hamburg and Pogonip limestones at the latter place is due to the continuation of the Jackson fault described by Mr. Hague. North of the Hamburg shale, in the Pogonip limestone, there is a large outcrop of quartz-porphyry, and still further on in the same rock a smaller overflow which is visible underground in the workings of the Bullwhacker mine. The dip of all the formations of Adams Hill, including the Secret Cañon shale, is apparently to the north.

Structure.—Although the mining explorations which have been made on Adams Hill are not sufficient to give a complete idea of its internal structure, they are, nevertheless, extensive enough to show that it is composed of a bed of limestone underlain and overlain by distinct beds of shale, all of which have a variable dip to the north. There is much less evidence of faulting and crushing in Adams Hill than there is in either Ruby Hill or Prospect Mountain. The rock does not seem to have been subjected to the enormous pressure that has caused the grinding up of the limestone in

those last-mentioned localities. On Adams Hill that rock is harder, more compact, and less subject to sudden changes in its physical characteristics. In many places the Hamburg limestone is capped by a conglomerate consisting of bowlders of limestone cemented together by a tough calcareous material. In this conglomerate fragments and even bowlders of ore are often found. This ore does not resemble in any respect the ores of Ruby Hill, and it is likely that it, as well as the accompanying limestone, are the products of the erosion of the immediate neighborhood, which have been cemented together by calcareous waters.

Ore deposits.—The deposits of this portion of Eureka District are as varied in regard to form as those of Ruby Hill, but in many other respects they differ from them. There is very little resemblance between them and true lodes, though they are all more or less connected with fissures and slips, and some of them which occur in the limestone near the shale seem to have a general course parallel to the contact of those formations. An instance of this occurrence can be observed in the Bowman mine, which lies near the Secret Cañon shale. Caves, which are so characteristic of Prospect Mountain and Ruby Hill, are rare; and although it is possible that such openings may exist in numbers, the explorations have not yet revealed them. It is true that the deepest mine workings have as yet attained but a moderate depth, not much exceeding 200 feet, although the explorations have been quite numerous. Nevertheless it is probable that if caves were numerous they would have been revealed before now, for it can be safely said they are of more frequent occurrence and usually of greater extent near the surface than at great depth. This is easily explained by the fact that the waters carrying carbonic acid, to which they owe their origin, becomes saturated with calcium carbonate as it descends, thereby losing its solvent power. The absence of caves, which in other portions of the district are so intimately connected with ore bodies, would seem to indicate that the genesis of these deposits was somewhat different from that of the ordinary class. This theory is also sustained by the fact that the ores are of a different character from those of Ruby Hill. The most noticeable difference is the prevalence of quartz ores. This can be said to be the distinguishing feature of the ores of Adams Hill, as well as those occurring in the Pogonip limestone on

the flat to the north, which is designated on the map as Mineral Point. The ores do not occur in compact form as the filling of chambers, but are found in bunches in cracks and seams in the limestone, and although masses of ore of considerable size are not unknown, they exist in the form of silicified limestone more or less impregnated with silver and lead minerals.

The ores.—The Eureka quartzite, which Mr. Hague has placed just above the Pogonip limestone, at one time covered the whole of Adams Hill, and there is still a small area of this rock to be seen on the northwestern slope of the hill near the road to the Wide West mine. It is not impossible that the quartz in the ore was derived from this quartzite. Still it is not likely, however, as it would be necessary for the silicious solutions, which were formed from this quartzite, to traverse the underlying Hamburg shale as well as the Pogonip limestone. Also, if the quartz in the ore was derived from the quartzite, it is likely that the ore was as well, as the two seem to have been deposited simultaneously, though this might possibly have occurred where the components of the ore were derived from different sources. The Eureka quartzite also carries small amounts of the precious metals; but the same objection to the secretion of the ore from this rock can be advanced that was offered in regard to the secretion of the ore in Ruby Hill from the outside country rock. It could hardly have passed through the Hamburg shale. It is possible, however, that the ore in the Pogonip limestone was derived from this source, though, as has been explained in Chapter VII., it is more justly referable to another source.

Another noteworthy fact in regard to the ores of Adams Hill is that they carry as a rule a high percentage of gold, although there are some that carry no gold whatever. The contents in gold is a distinctive feature of this region. Lead in the form of carbonate and sulphide is common, and both the Bullwhacker and Williamsburg mines have produced large quantities of this metal.

Quartz-porphyry as a source of the ore.—The quartz-porphyry which occurs in the Bullwhacker mine has already been mentioned (Chapter VII.) as the probable source of the ore in its immediate neighborhood. This porphyry still contains considerable quantities, relatively speaking, of gold, silver, and lead (see Chapter XI.), and although it does not cover a very extensive

area on the surface it is very likely that it may extend underground into Adams Hill. If this is the case, it has very likely been the source of the ore in the mines of that region. If it has been the source of the ore it is probable that the quartz has also been derived from it through the decomposition of its silicates.

Mining.—The ore of this region is usually of very good quality, but the rock is frequently hard and it is extracted with some difficulty. The mines have been opened by individuals and small companies, and they have not been sufficiently explored to determine either their permanency or their future value. Just at present there is not very much mining going on in this part of the district, but there seems to be no reason for believing that the deposits do not extend to considerable depth, and it is to be hoped that the decreased cost of mining and of reduction which inevitably follows the increasing age of a mining camp will cause the revival of this industry.

CHAPTER XVII.

FUTURE OF EUREKA DISTRICT.

Extent of the Prospect Mountain deposit.—The mining region of Prospect Mountain, comprised between Spring Valley on the west and the Secret Cañon road on the east, will no doubt produce large quantities of ore for years to come. As yet a beginning only has been made in the development of the deposits in this portion of the district. It is true that there are several mines, the Hamburg, Ruby-Dunderburg, and one or two others, which have been pretty well opened, though in all of these there is a great deal of ground which remains as yet in a virgin state, but in by far the majority of instances the claims of Prospect Mountain and vicinity have not been explored to any great extent. If the surface geological map is examined it will be seen that the two belts of limestone, which Mr. Hague has named, respectively, the Prospect Mountain and Hamburg limestone, are very wide; and although they cannot be regarded as ore-bearing throughout their whole extent, yet surface explorations have shown that the deposits contained in them are very numerous. Underground developments, as far as they have extended, have also proved that these deposits are continuous to a considerable depth. It is therefore very probable that numerous unexpected ore bodies will be discovered throughout this region in the course of future deep-prospecting operations.

Relative size of the Prospect Mountain and Ruby Hill deposits.—At first sight no reason appears why as extensive ore bodies should not be encountered in Prospect Mountain as have been found hitherto in Ruby Hill, but a careful examination of the structural features of the two regions leads to the belief that the ore bodies of the former locality will never reach the size of those of the latter.

It has been stated before that the opportunities for the deposition of ore have depended in a great measure upon the extent to which the limestone has been crushed and thus prepared for its reception and deposition. It cannot be said that such a shattering of formations has not taken place to a great extent on Prospect Mountain. It has, and its results are shown by the numerous fissures and zones of pulverized rock which are encountered in this region; nevertheless, the upheaval and faulting did not take place under conditions that were in every way as favorable as those which resulted in the present structure of Ruby Hill. The faults which brought about the present arrangement of the formations in the latter locality were accompanied by the formation of a fault-fissure which acted as a channel through which the metalliferous solutions entered the wedge-shaped mass of limestone lying between this main fissure and the quartzite. Whatever other part this quartzite may have played in the formation of the mineral zone of Ruby Hill, it certainly had the effect of confining the ore-bearing solutions to the crushed limestone bounded by the clay of the Ruby Hill fault. Had these solutions entered a mass of limestone of unlimited extent, although the amount of ore deposits might have been as great in the aggregate, it is not likely that ore bodies of a size equal to that for which this mineral belt has been noted would have been deposited. It cannot be denied that certain ore channels exist in Prospect Mountain, and that they are also confined in some instances between belts of shale, or between walls of limestone; yet, as far as present developments have shown, there has been no such limitation of the ore to a well-defined region.

Resources of Prospect Mountain.—These facts, however, need not prove a drawback to a careful exploration of the resources of Prospect Mountain. The Ruby Hill deposits were worked to a large extent when the cost of mining and reducing ores was far greater than it is at present, in spite of which they paid large profits; and a reduction in the cost of working-ores, coupled with the increased facilities offered by the tunnels and more systematic methods of mining, will compensate in a very great degree for any difference in the size of the ore bodies which may exist in the two regions.

Relative richness of the deposits of Prospect Mountain and Ruby Hill.—It is said that the ore of Prospect Mountain, as a rule, is richer than that of Ruby Hill. This

may or may not be the case. The only present means of determining the facts are by judging of the ore that is brought to the smelting works for reduction. The returns show that the ore of Prospect Mountain averages richer than that of Ruby Hill, but this is very likely owing to the fact that only ore of a high grade will pay for mining when the deposits are small, and cannot be taken, therefore, as a criterion of the value of all the ore in these mines.

Difficulty of making predictions.—What will be the future of the mines of Ruby Hill is very uncertain, and any predictions in regard to it must necessarily be inferences from the results of the explorations which have been made in the present lower workings. These explorations have not been carried sufficiently far to give indisputable indications as to the changes which may be expected in regard to the ore below the water-level. Moreover, the structural features in the lower levels of these mines have undergone a change, and it is impossible to tell with any certainty what effect they may have upon the general worth of these ore deposits.

Probabilities of finding ore in the lower workings.—The structure of the ore-bearing zone and the relation of the ore bodies to it have been fully described in the preceding pages of this report, down to a level, in the mines southeast of the compromise line, where the two fissures come together, and in the Richmond and Albion mines to a depth at which it is clear that they are approaching and will probably meet below. It has been stated that the bodies of ore in the Richmond mine have decreased in size as well as number below the sixth level. The ground, however, below this level, although it has been prospected to some extent, has not been sufficiently cut up to prove the absence of large ore bodies, and it is possible that the failure of ore is only apparent, and that future developments may expose large bodies. There is nothing in the nature of the limestone inconsistent with such a belief. The same may be said of that portion of the Albion ground which lies immediately northwest of the "A C" line. The ground in which the Albion shaft is sunk and that which lies west of it is unfavorable for ore, the limestone not resembling that which contains ore in other parts of Ruby Hill, while the faulting motion has not been great, and the limestone is therefore less disturbed. Even if ore should not be found in any quantities in these

two mines in the lower levels before the two fissures came together, this will not prove that no ore bodies are to be expected in the limestone which underlies the lower belt of shale. It will only prove that the limestone or the fissure system in this part of the hill was for some unknown reason unfavorable to the deposition of ore. It will be a very discouraging circumstance to the companies interested, but it may be expected. Large zones of barren ground have been known in the upper levels as well.

Conditions of ore deposition in the lower wedge of limestone.—If Plate VIII. is referred to, it will be seen that the lower mass of limestone is gradually widening out, as would inevitably be the case if the ideal section of Ruby Hill (Plate IV.) be true. The main fissure below the great limestone wedge has a hanging wall of crushed limestone which is overlain by a belt of shale. If the theory of the source of the ore stated in Chapter VII. is correct, the ore solutions passed upward through this fissure along the contact with the limestone, which offered all the conditions necessary to a deposition of the ore, provided the ore substituted itself for limestone. If such was not the case, and the ore was deposited in caves previously formed, there is little likelihood that this cave formation could have taken place in the lower bed of limestone, for the following reasons: It is certain that the caves in the upper limestone were formed after the faulting occurred which broke up this mass of rock and formed the main fissure. This main fissure with its wall of clay and the lower belt of shale effectually excluded any great flow of surface water into the lower belt of limestone, nor does the cave formation even in the upper limestone seem to have extended to the lowest points of this wedge of rock, probably because percolating surface waters became saturated with calcium carbonate upon reaching this depth. It is therefore improbable that caves of any great extent could have been formed at the depth at which this limestone lies. It will be seen, therefore, that the chances of finding any considerable bodies of ore in the lower limestone, if the ore deposition was dependent upon the prior formation of caves, are very few. But the evidence that the ore bodies were formed, at least in part, by substitution is very conclusive. There seems to be no probability that such a manner of deposition should be limited to a few hundred feet or to the upper mass of limestone.

The lower bed of limestone lying between the fissure on the quartzite and the lower stratum of shale affords almost equal structural facilities to the upper. It has been rent and crushed by the upward movement of the quartzite in a similar manner for a considerable distance, at least below the region where the lower stratum of shale was cut off by the fault. It would, therefore, offer every possible opportunity for the circulation of metalliferous fluids. Ore has also been found in the Ruby Hill fault-fissure at the place where it was cut by the drift from the 1,200-foot station of the Locan shaft. The flow of water was unfortunately so great, however, that it was not possible to determine the extent of this body. There thus seems to be no well-founded reason for believing that masses of ore do not exist in the lower stratum of limestone.

Whether the ore bodies will prove as large and as numerous as they have been above is a matter which cannot be decided from the limited number of facts which have been observed in the lower workings. Whether the extraction of this ore will be profitable will depend upon the flow of water, size of ore bodies, value of ore, and facilities with which it can be reduced. As to the size of the ore bodies, no satisfactory predictions can be made. No very great change in the value of the ore as regards silver need be feared. There will be poor ore bodies as well as rich ones, no doubt, but the ore is more likely to be somewhat richer in silver than the reverse, if there is any analogy between the ores of this district and those of a similar character in others where oxidation has taken place. With regard to the value in gold it is otherwise. The contents of the Eureka ores in gold has on the average been gradually decreasing as depth was attained, and it is but reasonable to suppose that this will be the case below the water-level. No entirely satisfactory reason can be given for this decrease in gold, but it is of very frequent occurrence in auriferous silver ores in many parts of the Great Basin. It was, however, not the case on the Comstock, and the change noticed in the ores of Eureka may be only a local one.

This fact need not necessarily be a cause of uneasiness, as there is no likelihood that the gold will give out altogether, and a slight reduction in the quantity of this metal present would not materially reduce the value of

the ores. While many geologists and many engineers believe that ore deposition is not limited to any depth within human reach, others are of the opinion that ore in considerable quantity usually occurs only within a moderate distance of the surface. This question, however, cannot be satisfactorily discussed from a theoretical point of view until much more is known of the chemical and physical conditions of ore deposition, nor as a matter of observation until far more thorough explorations have been carried on at great depths in mining regions. Some deposits have been followed to an immense depth (over 3,000 feet) without any diminution in yield; and if it were possible to gauge the erosion to which their croppings have been subjected since their formation, these and others would very likely yield more striking data. On the other hand, in many cases the search for ore below a certain depth has proved futile, but such cases afford purely negative evidence. Explorations at considerable depths are extremely expensive, and are rarely made on a large scale. It is consequently as yet impossible to say even of any single district that ore in paying quantities does not exist below a certain level, though it is certainly true of some that no indications of its existence have been found which would warrant the continuance of the search for it.

That the various companies owning these mines are fully justified in view of the former enormous production and the probabilities of finding ore in prosecuting a diligent though expensive search below the levels as yet reached seems to be beyond question.

As regards the future of Adams Hill and adjacent country, not much can be said; the mines have not been worked to any great depth or extent, and but few predictions can therefore be made in regard to them.

CHAPTER XVIII.

SUMMARY.

The following summary states in a condensed form the nature of the investigations described in the foregoing chapters and the conclusions to which they have led.

Description of Eureka District.—Eureka Mining District is situated on the western side of the Diamond Range, in the eastern part of the State of Nevada and south of the Central Pacific Railroad.

The district was discovered in 1864, but it was afterwards abandoned until the latter part of 1868, when mining operations were again begun.

The most important town in the district is Eureka, situated about 2 miles distant from the principal mines which are on Ruby Hill.

This hill forms the northern spur of Prospect Mountain, a ridge several miles long, which reaches an altitude of over 9,000 feet, and itself forms a spur of the Diamond Range. North of Ruby Hill lies Adams Hill, a low elevation distant something less than a mile. On these hills and on the mountain and its spurs are situated all the mines of any importance in the district.

As nearly as can be estimated the production of the precious metals up to the end of 1882 has been about sixty millions of dollars. It is difficult to ascertain the quantity of lead produced, but this is approximately 225,000 tons.

SURFACE GEOLOGY.

Mr. Arnold Hague has described the general geology of this district,[a]

[a] Abstract of Report on the Geology of the Eureka District, Nevada, by Arnold Hague. Third Annual Report of the Director of the U. S. Geological Survey. 1882.

but a reference to his results is necessary to a clear conception of the relations of the mines to the different formations.

The Cambrian, Silurian, Devonian, and Carboniferous are all represented in this district, though it is only in the rocks of the first two that metalliferous deposits of any kind have been found.

Formations.—Mr. Hague distinguishes the following beds in the Cambrian, beginning with the oldest: Prospect Mountain quartzite, Prospect Mountain limestone, Secret Cañon shale, Hamburg limestone, Hamburg shale. Those five formations have all been laid down conformably. The rocks of the Silurian in the order of succession are Pogonip limestone, Eureka quartzite, and Lone Mountain limestone. The rocks of the Devonian in this neighborhood are the White Pine shale and Nevada limestone.

Relations of the mines to the formations.—With the exception of the Hoosac mine in the Eureka quartzite, and the Bullwhacker and other mines in the Pogonip limestone on the slope north of Adams Hill, all the mines which have been discussed in this memoir are found in the Prospect Mountain and Hamburg limestones. No deposits whatever have been found in the Secret Cañon shale which separates these two beds, and although it is true that pyrite, both as impregnations and in masses, as well as distinctly-defined veins of quartz accompanied by calcite, have been found in the Prospect Mountain quartzite, the lowest of the sedimentary beds of the district, it has had no economic value. These occurrences, moreover, do not seem to be in any way connected with the deposits in limestone, and, as far as is known, there is no ore in the Hamburg shale.

Massive rocks.—The only massive rocks which make their appearance in the metalliferous zone which is occupied by Prospect Mountain and its offshoots are granite, quartz-porphyry, and rhyolite, but hornblende-andesite is found in its neighborhood. Quartz-porphyry, probably Mesozoic, appears in two places north of Adams Hill, and seems to be of earlier origin than the ore. Rhyolite is abundant in the neighborhood of the mines, as well as in immediate proximity to the ore. In some portions of the district it covers large areas, but in the mines it is only found in the form of dikes. Hornblende-andesite occurs near Hoosac Mountain, where it covers considerable territory, and basalt is found within three miles.

THE STRUCTURE OF PROSPECT MOUNTAIN.

Manner of upheaval.—Prospect Mountain and its adjacent spurs form an anticlinal fold, of which the axial plane is somewhat west of the crest of the principal ridge. The course of this plane is nearly due north and south except at Ruby Hill, where it turns towards the west. Evidences of bedding are so rare that it is often impossible to form an accurate idea of the prevailing angle of dip. When the formations which at present compose the mountain were folded and uplifted, an enormous crushing and grinding force was exerted upon the different members of the series. Those rocks, such as the shales, which were flexible were much twisted and distorted, but retained their original character. The limestones, on the other hand, were much crushed and fissured, and faulted in many directions. Most of the fissures were found parallel to the axis of fold, and as the uplifting and crushing continued great zones of limestone were ground almost to powder.

Influence of eruptive rocks.—Subsequently to the primal folding the various eruptions, especially that of rhyolite, had a further disturbing effect upon the structure of the country. Many fissures and faults have unquestionably been caused by the eruption of the rhyolite, and, as will appear later, it had a direct influence upon the deposition of ore.

The only known occurrence of granite in the district is on Mineral Hill at the north end of Prospect Mountain. It is probable that this mass formed a submarine hill upon which the quartzite, limestone, etc., were laid down, and that its exposure in its present position is due to erosion after upheaval had taken place.

Bowlders resembling this granite have been taken from the quartzite in the Richmond shaft. The strata of the formations which compose Prospect Mountain usually dip away from the axial plane of the fold, though there are notable exceptions to this rule.

Section of Prospect Mountain through Eureka tunnel.—The best opportunity for studying the formations on the eastern slope of Prospect Mountain is given by the Eureka tunnel, which has been driven from a point near the head of the west branch of Goodwin Cañon in a nearly due west direction into the heart of the mountain.

The following are the different formations encountered, in the order of their succession from the mouth of the tunnel:

85 feet mineral limestone[a]	Hamburg limestone.
290 feet shale	Secret Cañon shale.
935 feet mineral limestone	Prospect Mountain limestone.
30 feet shale[b]	Prospect Mountain limestone.
51 feet mineral limestone	Prospect Mountain limestone.
460 feet shale	Prospect Mountain limestone.
90 feet stratified limestone	Prospect Mountain limestone.
50 feet mineral limestone	Prospect Mountain limestone.

At various points along its course the tunnel cuts through seams and fissures, which generally cross it at right angles. Their usual pitch is easterly, though there are many exceptions to the rule. The msot prominent one of these fissures is at a point 840 feet from the mouth of the tunnel. It dips nearly vertically, perhaps a little inclined to the east. It is open in places and filled with sediment, bowlders, etc., which have been washed in from above. At the point where it is encountered it is about 350 feet below the surface, and it is a characteristic example of numerous occurrences of the same kind both in the mountain and in Ruby Hill. Like many others, it has been accompanied by ore which was formed on the west side of the tunnel. Faulting has occurred on most of these fissures, and it is safe to say that the portions of country which lie west of the fissures or upon the foot-wall side have as a rule been relatively raised, and the strata have reached their greatest relative elevation just over the axis of fold.

The stratified limestone in the end of the tunnel pitches west at a steep angle where first encountered, but gradually becomes flatter until a little distance west of the summit its stratification is nearly horizontal.

Section of Prospect Mountain through Prospect Mountain tunnel.—The Prospect Mountain tunnel, starting at a point about 2,700 feet west of the summit, nearly opposite the Eureka tunnel and several hundred feet below it, has been driven over 2,350 feet into the mountain. For the first 1,400 feet it passes through a hard, compact, white limestone, which in places resembles marble. This

[a] "Mineral limestone" is the term employed in the district to designate the broken and metamorphosed rock almost invariably connected with ore.

[b] The term "Prospect Mountain limestone," of course, refers to a group of beds characterized by the presence of certain fossils. Though limestones predominate, the intercalated shales are necessarily classified as members of the same group of beds.

limestone is not often fissured, but contains some cavities excavated by water. There is nothing about it to indicate that it is mineral limestone. At a distance of 1,400 feet from the entrance a fissure is encountered nearly at right angles, which dips 80° to the west. From this point the character of the limestone changes; it is much more broken, and many of the ordinary varieties of mineral limestone are found, as well as seams, crossing the course of the tunnel. At 1,835 feet ore was discovered, but as yet the deposit has not proved valuable. At about 2,100 feet stratified limestone was encountered along a fault-seam which dips to the west, and at 2,250 feet shale makes its appearance along a similar seam (see Plate II.). It is probable that this shale is the same body as that encountered toward the end of the Eureka tunnel. All of the rock encountered in this tunnel belongs to the Prospect Mountain limestone.

General internal structure of Prospect Mountain.—It will be noticed (Plate II.) that the west side of the mountain differs greatly from the eastern. This in some measure is owing to the fact that a larger portion of the overlying rocks have been eroded, and that the axis of fold lies somewhat west of the ridge.

Distribution of ore in Prospect Mountain.—The larger portion of the mountain and its adjacent spurs is composed of mineral limestone, and evidence of the number of metalliferous deposits contained in it is offered by the numerous outcrops of gossan which occur along its whole extent, but which are particularly numerous from Ruby Hill to the Secret Cañon divide. With the exception of some few mines, the properties of Prospect Mountain have been but slightly developed. Those, however, that have been opened to any great extent show that there are numerous masses of ore contained in the Hamburg as well as the Prospect Mountain limestones, although no bodies of such a size as those discovered in Ruby Hill have been found.

THE STRUCTURE OF RUBY HILL.

The formations of Ruby Hill.—The position of the different formations on the surface of Ruby Hill, and the relations that they bear to the granite of Mineral Hill, can be observed by a reference to the geological map of the district. The limestone of these two hills formed one and the same body

before erosion, and it is merely the continuation of the long belt of limestone of which the greater part of Prospect Mountain is composed.

The main beds of Ruby Hill are a mass of quartzite, which is probably underlain by the granite of Mineral Hill; a broad zone of mineral limestone and an overlying belt of shale. All of these beds have been tilted so that they stand at an angle of about 40°, though nowhere on Ruby Hill does the dip of the stratification of any of the beds conform to the dip of their planes of contact. This lack of parallelism is characteristic of the region of Ruby Hill, and is due to a succession of faulting movements. There are two systems of fault-fissures on Ruby Hill. The first consists of those which are approximately parallel to the strike of the formations, and which were produced entirely by the main folding and upheaval, and the second made up of those which were caused by the same forces supplemented by strong lateral pressure.

That there has been lateral pressure exerted from a northeasterly direction at some time is shown by the direction of the striation marks observable on these latter faults, which have been called cross-faults. Beginning at the Jackson mine at the southeast, the strike of the formations is to the north, but it is soon deflected to the west until in the Albion mine it is nearly due west.

The quartzite and limestone contact.—The line of the contact of the quartzite and limestone on the surface of Ruby Hill represents very nearly the crest of the anticlinal fold. Underground, this contact is extremely irregular. Besides smaller irregularities in the quartzite there are three large protrusions along the course of this contact, which occur respectively in the Phœnix, K. K., and Richmond mines. Along the line of dip of the quartzite and limestone contact there is a great depression several hundred feet in vertical extent, which occurs at about the same depth in all the mines, and which combined with undulations along the line of strike forms large basins. These basins are intimately connected with the ore bodies and will be referred to later.

The main fault.—The most important structural feature of Ruby Hill is a fault which at the southeastern end of the mineral zone is first to be seen at the American shaft. (See Plate III.) From this point, this fault, which

has been called the Ruby Hill fault, though not perceptible in many places on the surface, passes west of the Jackson hoisting works, its course veering toward the west, and is visible in a tunnel near the Phœnix line. It passes northeast of the Phœnix, Lawton, and K. K. shafts, but must be very close to the latter. It can next be seen near the mouth of a tunnel run to connect with the Bell shaft. The last place where it can be observed on the surface is near the Richmond office. Although this fault is not continuously traceable above ground owing to the *débris*, its existence is fully established by the fact that it is encountered at numerous points in the underground workings of all the mines of Ruby Hill. The average dip of the plane of this fault is about 70° northeasterly, and it is of remarkable uniformity, scarcely ever varying 5° one way or the other. Its course, also, is extremely direct, with the exception of the bend between the Phœnix and Jackson. This Ruby Hill fault is marked by the presence of a fissure filled with rhyolite and clay which is widest in the Jackson and Phœnix, where in places it measures as much as 15 feet. In these two mines it is filled with rhyolite, which, although much decomposed, is still easily recognizable. In following the fissure west the clay is found to be more calcareous, and in the K. K. and Eureka positive proofs of rhyolitic character are lost. In the Richmond mine the fissure is narrow, and although a distinct and well-defined seam is only a few inches wide.

The main fissure.—This fault fissure has been called the main fissure, as to its formation are due the most important features of the present structure of Ruby Hill. A proof of its comparative recent formation is the fact that it faults all the formations with which it comes in contact, but is itself nowhere faulted. It is evident that the country southwest or on the foot-wall side of this fault has been raised many hundred feet above its hanging wall. The distance has apparently been greatest in the Eureka, where it has certainly exceeded 1,400 feet. (See Plate VIII.)

The dip of the quartzite and limestone contact does not greatly exceed 40°, while the dip of the main fissure is about 70°. The two surfaces of motion therefore approach each other, and the line of junction is exposed at various depths in the lower workings of all the mines except the Richmond and Albion. In these mines the lowest workings have not yet reached

the junction. The face of the quartzite when in contact with the fissure is no longer the original contact of quartzite and limestone, but is the fault face of the southwestern uplifted country. (See Plate IV.) It is evident that if the fissure continues downward with its present dip, at some depth it must enter the quartzite.

The secondary fissure.—At the time of the disturbance which produced the Ruby Hill fault, another and secondary fissure was formed along the contact of the quartzite and limestone, and the quartzite was raised higher than the limestone, giving rise to the formation of a wedge of limestone between the quartzite and the main fissure. Up to the present time all the ore of any importance taken from Ruby Hill has been extracted from this wedge of limestone, the crushed condition of which is due to the upward movement of the southwestern country against the hanging wall of the main fissure. Section 7, Plate VIII., is typical of the relations of the two fissures to each other and to the quartzite, limestone, and shale in the mines southeast of the "compromise line."

The two belts of shale.—Two belts of shale, only one of which appears on the surface, are known to exist in Ruby Hill. The upper or surface shale can be observed on the map, Plate I. Taking into account the general dip of the surface shale and that of the shale where it is encountered below, it is at once apparent that the two must be distinct masses in all the mines southeast of the compromise line. In the Richmond mine, however, it is different. The shale on the surface in which the shaft is sunk is the same body of shale that is encountered below. The manner in which the Richmond shale and the lower belt of shale have been brought together in the lower workings of the Richmond and Eureka, and the manner in which this lower shale has been faulted, have been fully explained in the body of this report.

Influence of the main fissure on the ore formation.—The time and manner of the formation of the Ruby Hill fault and its subsequent filling either with rhyolite or clay are matters of very great importance as regards the mineralization of the limestone between the quartzite and this fissure, and the prospects of finding ore either at a greater depth or by prosecuting developments in the so-called "front limestone." This body of rock lies northeast of the

main fissure, and although it has in many places the appearance of ore-bearing ground has hitherto been found unproductive, all the ore having been obtained from the wedge of limestone between the main fissure and the quartzite. It is true that the prospecting done in the front limestone has not been sufficient to prove that it contains no ore bodies, but it has been sufficient to discourage search in that direction.

As far as prospected, the front limestone does not exhibit the crushed condition that is so apparent in the wedge of limestone between the quartzite and the main fissure.

The quartzite in the Richmond.—The quartzite southeast of the Richmond shaft appears to be a solid mass many hundred feet thick. Its contact with the limestone is very irregular, and the rock near the surface is often displaced to a greater or less extent by faults, but it is comparatively easy to explain these irregularities and to account for the phenomena exhibited. Not so, however, with the quartzite in the Richmond and Albion ground northwest of the working shaft of the former mine. The quartzite in these two mines consists of a narrow band from a few inches to 90 feet wide, which bends and twists in many directions. It accompanies the secondary fissure which leaves the face of the main body of quartzite somewhere near the Richmond shaft.

Formation of the narrow quartzite.—The manner in which the narrow band of quartzite found its way into its present position seems to admit of but one solution, namely, that its occurrence is due to a fault or a succession of faulting movements which followed the line of the accompanying fissure, and that it originally formed part of the main body of quartzite, which must here underlie the limestone. It is altogether improbable that it constituted a distinct bed of quartzite laid down upon the back limestone. In this case some indications of its existence would have been noticed in other parts of Ruby Hill. It is not possible that it is quartz, and was deposited after the formation of the fissure, as under the microscope it exhibits the structure of quartzite.

Back limestone.—The term "back limestone" is given to the limestone which is found on the foot-wall side of the narrow band of quartzite. This rock differs in many respects from the limestone which is encountered between

the quartzite and shale. As yet no ore of any kind has been found in it. Its peculiarities are very characteristic, and it is easily recognizable wherever found.

The Jackson fault.—The main fissure joins a fault which Mr. Hague has called the Jackson fault, somewhere near the American shaft.

ORES OF EUREKA DISTRICT.

Minerals.—The following minerals have been noticed in the ores of Eureka District: Galena, anglesite, cerussite, mimetite, wulfenite, limonite, calamine, smithsonite, calcite, siderite, aragonite, quartz, steatite, blende, pyrite, arsenopyrite, molybdenite, malachite, azurite, and wad. The lead minerals are well represented, and it is highly probable that most of the known varieties exist in greater or less quantities in the ores, although the presence of all of them has not been detected. Antimony is present in many ores, but in what form has not been determined. Silver and gold are present; silver in the form of chloride and sulphide, and gold probably in the metallic state. Down to the somewhat irregular water-line the ores are substantially oxidized, and consist mainly of lead carbonate and sulphate carrying precious metals, and accompanied by ferric hydrate. The average tenor is 15 per cent. lead, 0.079 per cent. silver, 0.00248 per cent. gold. Quartzose ores are rare, but when found are important as a flux for the ordinary basic variety. The various classes of ores recognized by the miners are described in Chapter V., but may be omitted here.

Classification of the ore deposits.—The ore deposits of Eureka District, though they contain gold, can be classed under the head of silver-lead deposits in limestone. The type of deposits to which those of Eureka belong is one often met with in the older limestones of the Great Basin, and although these particular deposits have been of more value and are more widely known than any of the others, and exhibit some very interesting structural features, they cannot be said to form an isolated class.

The lead deposits of the Great Basin in general, and those of Eureka in particular, have some points in common with all the known varieties of lead deposits in the world, but the resemblance is not sufficient to allow any one of these to be taken as a prototype of those of Eureka. As re-

gards the ores and their manner of formation, the Leadville deposits of Colorado, described by Mr. Emmons,[a] resemble those of Eureka most, but the two regions differ widely in respect to the structure of the country and the relations of the deposits to the different formations. A classification of the ore deposits of this district, as regards their form, is a matter of considerable difficulty. Some of them may be termed fissure or contact veins, but in most cases they are very irregular in form and are better described by the German word "Stock" than by any mining term used in English. They are often lenticular, but this word cannot always be used to describe them, as they often have offshoots in all directions. Any classification, however, that is dependent on mere differences of form must be more or less unsatisfactory.

Distribution of the ore bodies.—The ore bodies do not seem to follow any particular direction either as regards dip or strike, and at first sight they appear to be distributed throughout the ore-bearing formation without any regularity. This is not wholly the case; and although no well-defined law can be found governing their occurrence, this is connected with that of certain phenomena in the country rock, such as fissures, caves, and broken limestone.

Formation of the ore bodies.—The distribution of the ore has been determined almost entirely by the physical character of the limestone in which it is found, and not by any chemical or mineralogical differences in the rock. The greater facilities offered by a crushed and broken limestone, no matter what its character, to the percolation of metal-bearing solutions would more than compensate for any chemical advantages which a particular kind of limestone might offer. During the process of upheaval to which Prospect Mountain and Ruby Hill were subjected, the limestone was fissured and crushed, great zones of shattered rock being formed, which are separated here and there by unbroken belts. The ore-bearing solutions entered the rock through the channels of least resistance, the crushed limestone offering fewer obstructions than the fissures themselves, and deposition followed in forms of a degree of irregularity corresponding to the complexity of the preceding dynamical effects.

[a] Second Annual Report of the Director of the U. S. Geological Survey, 1881.

Rearrangement of the ore by water.—From the disposition of the ore in a stratified form in the upper part of many of the large ore chambers it is evident that it owes its present position to rearrangement by subterranean water currents. This occurrence has been of comparatively recent date, as the ore has been thus deposited since its oxidation.

Connection of ore bodies with fissures, etc.—Ore bodies are intimately connected with the occurrence of fissures, caves, sediment, and on Ruby Hill with depressions in the quartzite. The ore bodies at first sight often seem to have no connection with any fissure or channel through which they could have been filled, but such a connection has been demonstrated in so great a number of cases that it may be presumed to have existed in all. In by far the greater number of instances the fissure has led to the discovery of the body, or the existence of the fissure has been shown in the workings subsequent to the discovery of ore. Sometimes it has been almost obliterated by pressure, and in others it has not been revealed by the explorations of the miner.

Caves.—Caves are found in many places in the limestone, and no large ore body has been found which had no cave over it, but caves are by no means always accompanied by ore bodies.

Depressions in the quartzite and ore.—The manner in which the depressions in the quartzite on Ruby Hill occur has been already explained. That large ore bodies should be of frequent occurrence in these depressions is not strange, when it is remembered that the limestone in them was in a shattered and crushed condition, and that the quartzite with its casing of clay served to a certain extent to confine the metal-bearing solutions to the limestone mass, where large quantities of these solutions were probably allowed to settle quietly and deposit ore.

Relations of the ore bodies to the formations.—On Prospect Mountain there are no workings in the neighborhood of the quartzite, and thus far the metalliferous zones have been separated by belts of undisturbed limestone and shale. The size of the ore bodies in the mountain has been much smaller than those on Ruby Hill, and the caves have been smaller and less numerous.

In the mines on Ruby Hill, southeast of the "compromise line," the ore bodies usually occur connected with the quartzite, but in the Richmond and Albion they are almost always far removed from it.

SOURCE OF THE ORE.

Possible sources of the ore.—The possible sources of the ore are a deposition in small particles with the limestone, the ore being afterwards segregated into nearly isolated bodies either by chemical or mechanical action; a segregation of the ore in the limestone from the country rock on either side of it; and a deposition from solutions which came from below.

Precious metals in the different rocks.—Several series of assays made with extraordinary precautions show that the stratified limestone contains only the minutest traces of silver, while the mineral limestone, especially where it is iron-stained, contains a number of cents per ton. The silver contents, however, on the whole, diminishes as the distance from the ore bodies increases, and nowhere answers to the composition which the rock must have possessed had the ore bodies been derived from it. The trace of silver in the limestone is an impregnation from the ore bodies. The shale never carries more than a trace of silver and gold, and the quartzite could not have furnished the material of the ore bodies. There are also good structural reasons for believing that the ore cannot have been formed by segregation from the surrounding rocks. Neither do the examinations furnish any reasons for believing that either the granite or the rhyolite yielded the metallic compounds of the ore bodies.

Quartz-porphyry as a source of the ore.—On the other hand, the quartz-porphyry proves to contain silver, gold, and lead in no inconsiderable quantities, and has manifestly been subjected to chemical action involving the solution of a portion of its metallic contents. Of this the decomposition of the rock, combined with a notable concentration of silver and gold in the pyrite (which is of secondary origin), are evidences. While the quartz-porphyry appears on the surface only in a small area, it is entirely possible that the mass underlies a great part of the district, and that it may have yielded the ore which was deposited in the limestone. This, however, is uncertain, while it is tolerably safe to say that of all the rocks which appear at the

surface the quartz-porphyry is the only one which can have furnished the metals of the ore bodies.

The solfataric action and the ore formation.—The manner of occurrence of the ore and its connection with the fissure system are consistent only with the supposition that whatever the source of the ore may have been, it reached its present position in ascending solutions. The formation of the ore-bearing solutions is almost certainly due to the solfataric action arising from the eruption of the rhyolite. The intrusion of this rock was the last dynamical disturbance on Ruby Hill, for the main fissure with the rhyolite dike faults all formations with which it comes in contact, except the ore bodies, and is itself nowhere faulted. The rhyolite dike also shows every evidence of solfataric decomposition. There is no evidence of two distinct periods of solfatarism, and unless the ore formation and the alteration of the lava are due to comparatively late volcanic agencies, which have left no other trace of their existence, the ore deposition and the eruption of rhyolite must have been related phenomena.

MANNER OF THE DEPOSITION OF THE ORE.

The deposition of the ores.—The solutions containing the ore penetrated the limestone, passing through fissures and interstices in the broken rock, and deposited the ore where conditions of temperature and chemical activity were favorable to its precipitation. It is impossible to determine what may have been the chemical composition of the solutions which carried the ore, but it is not improbable that they consisted in great part of metallic sulphides dissolved in alkaline sulphides. These solutions were necessarily formed under the influence of heat and pressure. Rising into the shattered limestone at a diminishing pressure and temperature, the liquids lost much of their solvent power and many of the metals that they contained were precipitated. This precipitation could have occurred in only two ways: either through deposition in pre-existing large cavities or through a substitution of ore for country rock. The manner in which the deposition took place has a very important bearing upon the probabilities of finding ore at any considerable distance below the water level.

The formation of caves.—The formation of caves in limestone is usually attributable to the action of waters percolating from the surface and carrying carbonic acid in solution. To form a cave at a given spot, water containing free carbonic acid must be supplied in sufficient quantities, and an escape must be provided for the more or less saturated solution of calcium carbonate. Caves cannot, therefore, form at an indefinite depth from the surface, and their practical limit is reached at the water level. The caves in Eureka are of more frequent occurrence near the surface than in depth, and they are not found at all below the water level. If the theory of a simple deposition of minerals from solutions in pre-existing caves were correct, it is evident that the limit of the ore would be reached at the point where cave formation was no longer possible.

The substitution theory.—In the Eureka deposits nothing has been observed which would indicate that the ore had been crystallized from solutions in pre-existing cavities. The banded and concentric structure, characteristic of that manner of deposition, is nowhere visible, and although it is conceivable that it might have been obliterated in the oxidized ore bodies, it is impossible that such should have been the case in the unchanged masses of sulphurets. The masses of sulphurets on the other hand offer strong evidence in favor of the theory of substitution. The minerals have replaced the limestone in such a manner that they have often retained the structural form of that rock. Rounded bowlders of limestone have also been found as the nucleus of masses of ore.

The sulphuret ore shrinks to some extent owing to the leaching which follows oxidation, and this accounts for the apparent relative size of many of the caves over ore bodies. These caves were no doubt subsequently considerably enlarged by the waters bearing carbonic acid. If the deposition of ore is correctly referred to the solfataric action consequent upon the rhyolite eruption, it is likely that the precipitation of the sulphurets began soon after the outburst of volcanic rock, and before there could have been much cave formation.

That the lead deposits of Raibl (see Chapter VIII.) and of other places should not have been formed by substitution is not an argument which would prove that the same was the case in Eureka. In the Leadville de-

posits, which in many respects resemble those of Eureka, the ore has been substituted for limestone, according to Mr. Emmons.[a]

Preponderance of evidence in favor of the substitution theory.—Weighing the evidence on both sides of the question, it appears that a large part of the ore was brought into its present position by substitution, while it seems impossible to demonstrate that any part of it was deposited in pre-existing cavities. It is highly probable that all the ore was deposited by substitution, and that future developments will effectually establish the fact.

ASSAYING.

Object of assaying country rock.—With a view to discovering, if possible, the source of the ore in the mines of Eureka District, numerous and careful assays of all the different kinds of country rock in the neighborhood of the ore bodies were made. As the quantity of the precious metals contained in any of these rocks is extremely small, it was necessary to take unusual precautions in order to determine with any degree of exactitude the amounts of gold and silver present. Assayers do not ordinarily attempt to estimate with accuracy any value of either gold or silver less than one dollar to the ton (0.0026518 per cent.), and as the country rock of this district never contains so much as this, particularly delicate methods were required in the determination of the actual quantities of these metals.

Accuracy of the process of assaying.—The process by which the results given in this report were obtained have been fully explained in the chapter on assaying, and it is only necessary to state that it was found possible to determine the value of silver in any country rock within a cent and a half. It was not possible, however, to determine the gold value with equal accuracy, as the quantity of it was extremely small; and it was neglected in most cases.

Use of assays.—While various purposes may be subserved by assays of country rocks, the main objects of those described in this report were, first, to ascertain in which of the rocks the precious metals could be detected, and, second, to trace the variations of tenor in different occurrences of the same rock. As a qualitative method, exception can scarcely be taken to the

[a] Second Annual Report of the Director of the U. S. Geological Survey.

dry assay, while even if the degree of accuracy reached in determining the absolute contents in precious metals of the Eureka rocks has been over-estimated, the value of the results would scarcely be impaired, for it will hardly be denied that the results form a sufficient basis for a comparison of different samples of the same rock, all containing very small quantities of silver and gold. For the purposes of this report it makes little difference whether a certain mass of limestone really contains 10 cents or 20 cents, if it can be proved that a second body of limestone contains twice as much, or, it may be, half as much. In other words, the main purpose was to ascertain the relative contents, not the absolute contents, of the samples assayed. Even if the methods employed were ideally exact, it would be impossible to calculate the metallic contents of large blocks of ground with precision, since it would be impossible to obtain samples which should correctly represent the average of the mass.

PROSPECTING.

Methods of prospecting.—There is nothing remarkable about the methods of prospecting in the Eureka District. On Prospect Mountain it consists in following seams or fissures in the limestone which show indications of ore, or in sinking shafts and driving levels in different directions in that rock. At present Prospect Mountain is being explored by a system of tunnels, which method, owing to the nature of the ground and the relation of the claims to each other, offers some advantages. On Ruby Hill the shafts are sunk in the zone of mineral limestone between the quartzite and shale, and prospecting is carried on by cross-cutting between the two last formations, particular attention being paid to the following of fissures and broken ground. Caves, as well as stained limestone, are usually considered an indication of ore.

Earth currents and assays in relation to prospecting.—It cannot be said that the electrical experiments made by Dr. Barus in the Eureka mines have as yet led to any decisive results as regards the indication of the presence of ore bodies. There is, however, a remarkable coincidence in the results obtained by Dr. Barus with those obtained from assays of country rock along a line leading up to an ore body. In both cases the presence of the same body was indi-

cated as it was approached, although the indications were not so pronounced that they might not have been caused by qualities of the rock independent of the ore body itself.

As yet no practical benefit has been derived either from the electrical experiments or from the assays of country rock. This is partially due to the fact that neither of those methods of search have been sufficiently developed to give definite results. As regards assaying, it may be said that although the indications are often indefinite, this method can be carried out with comparatively little expense and with little loss of time, though great care must always be used in making the assays and in employing the resulting values.

FUTURE OF EUREKA DISTRICT.

Future of Prospect Mountain.—The mining region of Prospect Mountain comprised between Spring Valley on the west and the Secret Cañon road on the east will no doubt produce large quantities of ore for years to come. Though several of the mines of this portion of the district have been developed to a considerable extent, there remain a great many claims which are still in a virgin state. Underground explorations have proved that many of the deposits are continuous to a considerable depth. It is therefore very probable that numerous unexpected ore bodies will be discovered throughout this region in the course of future deep prospecting operations. The ore bodies of Prospect Mountain, however, are not likely to be as large as those of Ruby Hill, owing to the structure of the country. Taking into consideration the height of the mountain and the fact that no quantity of water has been encountered even at a depth of over 800 feet, no trouble need be anticipated from that source for some time to come.

Future of the mines of Ruby Hill.—What will be the future of the mines of Ruby Hill is very uncertain, and any predictions in regard to it must necessarily be inferred from the results of the explorations which have been made in the present lower workings. These workings have not as yet given any certain indications of the future. The probability of finding ore in the lower wedge of limestone depends in a great measure upon the validity of the theory of substitution. If this theory is the true one—and the proofs

favoring of it are strong—there seems to be no reason for doubting the presence of ore below, provided that the limestone was in a fit state to admit the ore-bearing solutions during the period of deposition. That this was the case is indicated by what has been thus far observed in the lower limestone and by the fact that ore was found in the Ruby Hill fault-fissure when it was laid bare by the cross-cut from the 1,200-foot level of the Locan shaft. On the other hand, if the ore bodies were dependent upon the prior formation of caves they will not be found below the water-level, as cave formation could not take place much below that plane.

Whether the extraction of the ore in the deeper workings will prove profitable will depend upon the flow of water, size of ore bodies, value of ore, and facilities with which it can be reduced. Water may prove a serious impediment, but it is not necessarily one which should be fatal to the exploration of these mines. As to the size of the ore bodies no satisfactory predictions can be made. No great change in the value of the ore as regards silver need be feared, though it is possible that the contents in gold may decrease.

INDEX.